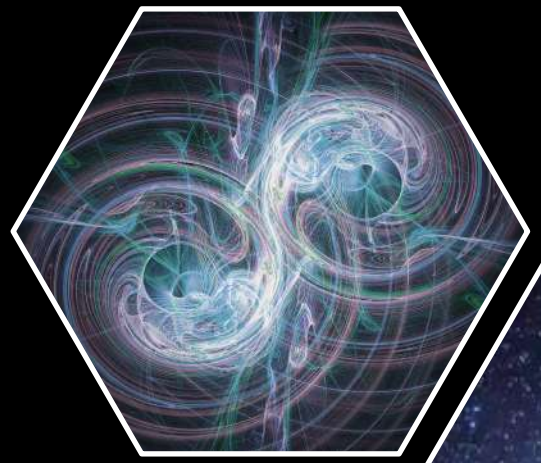


Reconstructing Neutron Star Masses from Metal-poor Stars

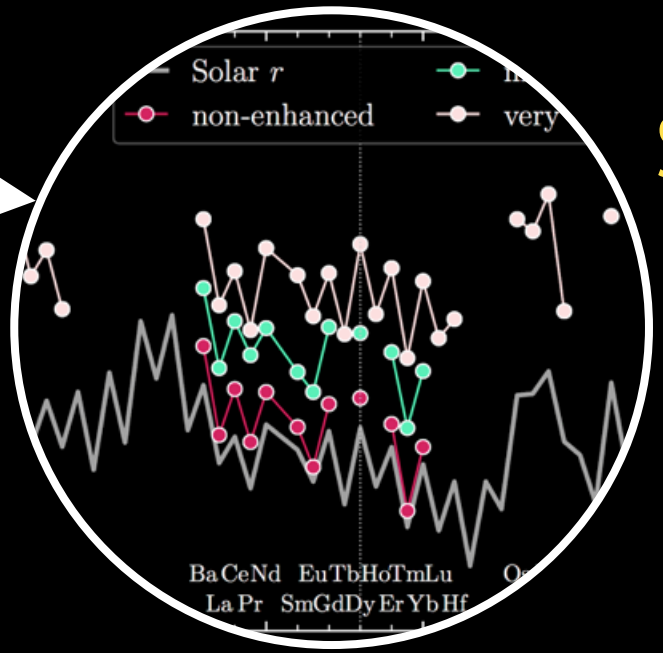
Erika M. Holmbeck

Nuc2021 | 28 July 2021

Holmbeck, Frebel, McLaughlin, et al. 2021, ApJ, 909, 21

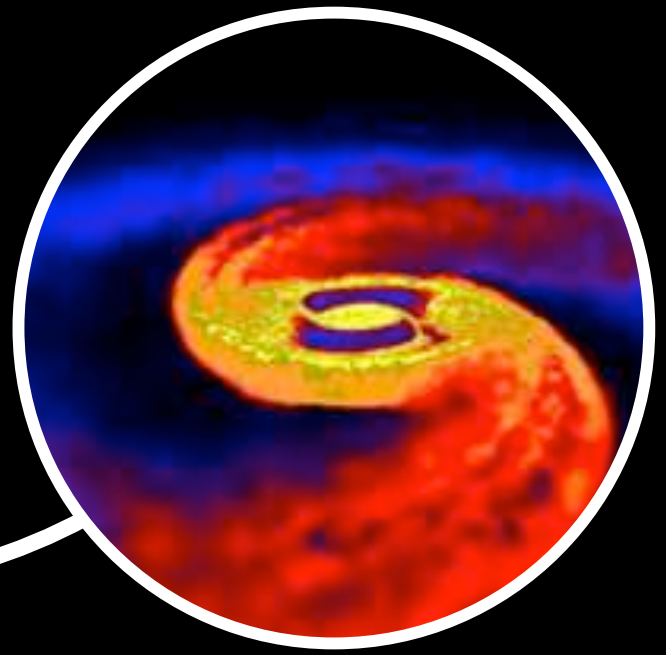
RIT | Rochester Institute of Technology

Star-forming gas



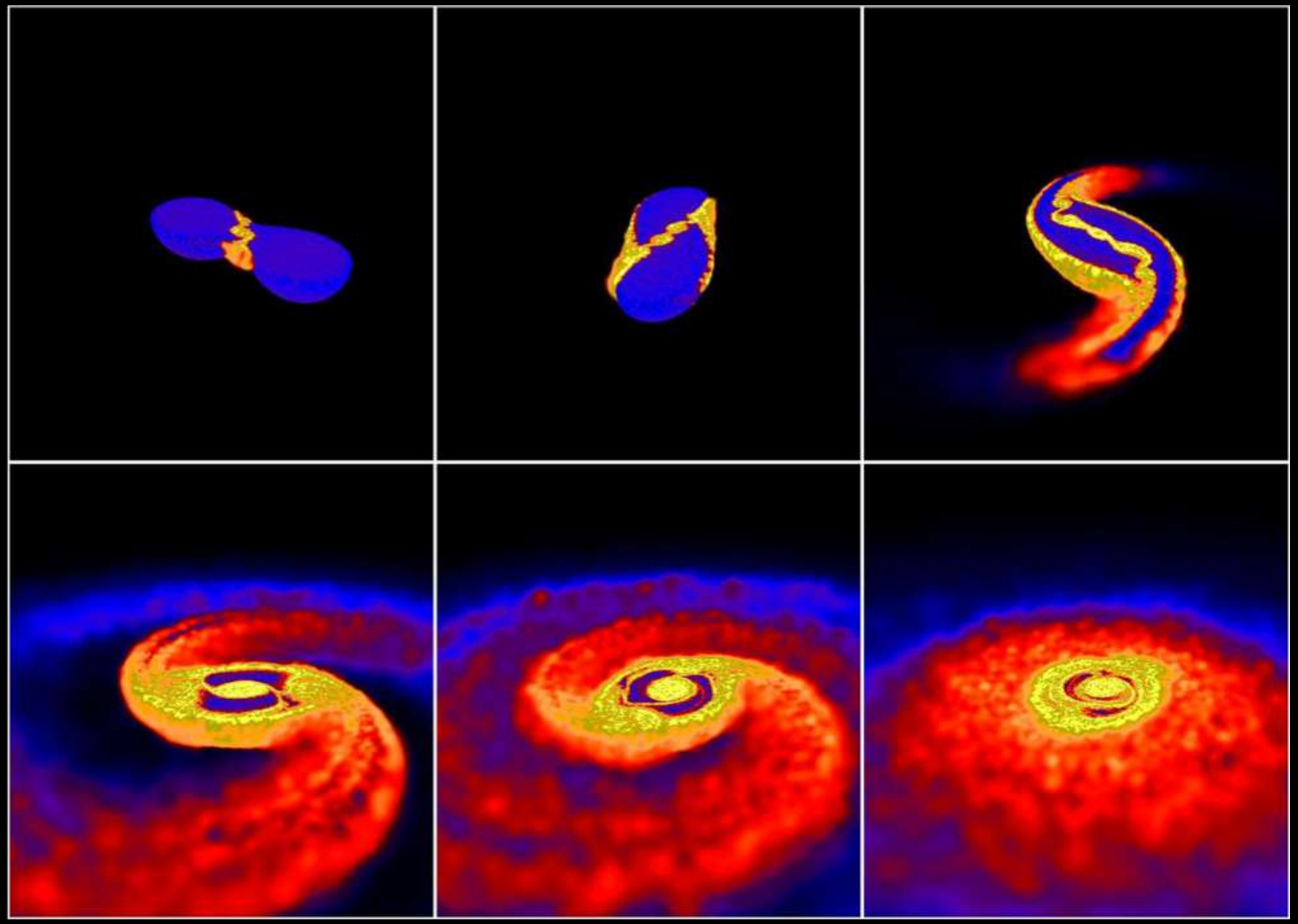
Stars with *r*-process signatures

Enriches the inter-stellar medium



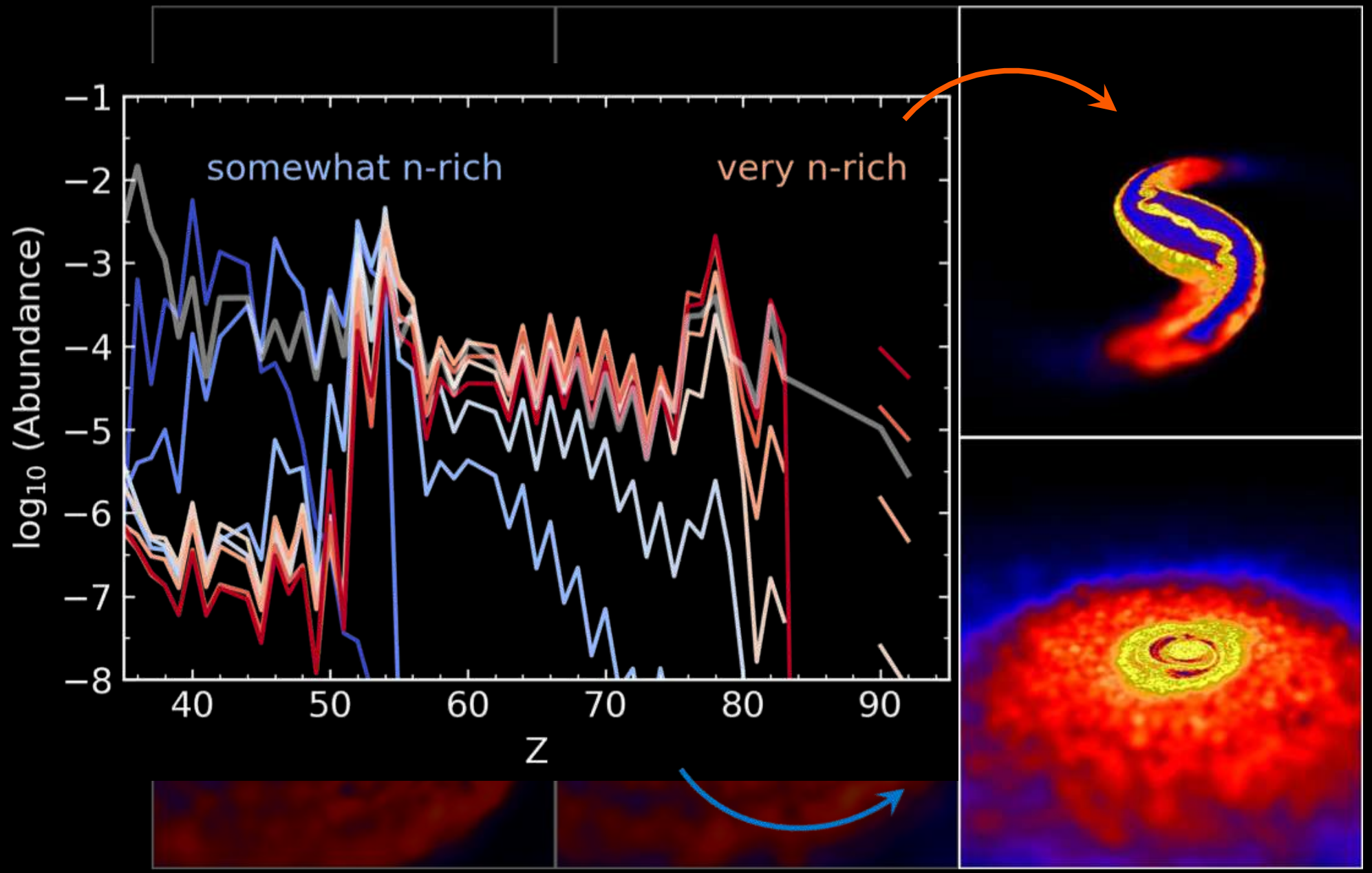
Merger ejects *r*-process material

NSMs eject material through primarily two mechanisms



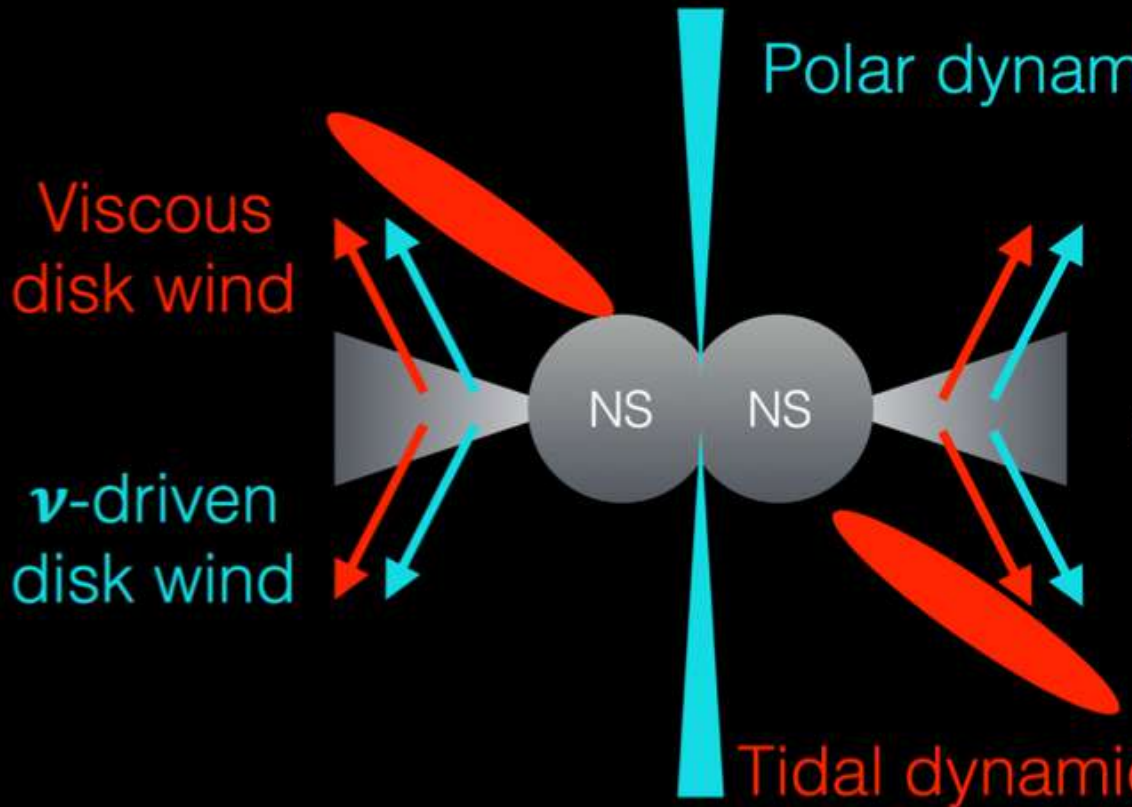
Price & Rosswog (2006)

NSMs eject material through primarily two mechanisms



Price & Rosswog (2006)

NSMs should not make identical r-process yields



The ratio of light and heavy r-process elements should vary in neutron star mergers

and thus also in metal-poor r-process stars!

Blue: high Y_e, neutron-poor, **light** 1st-peak r-process

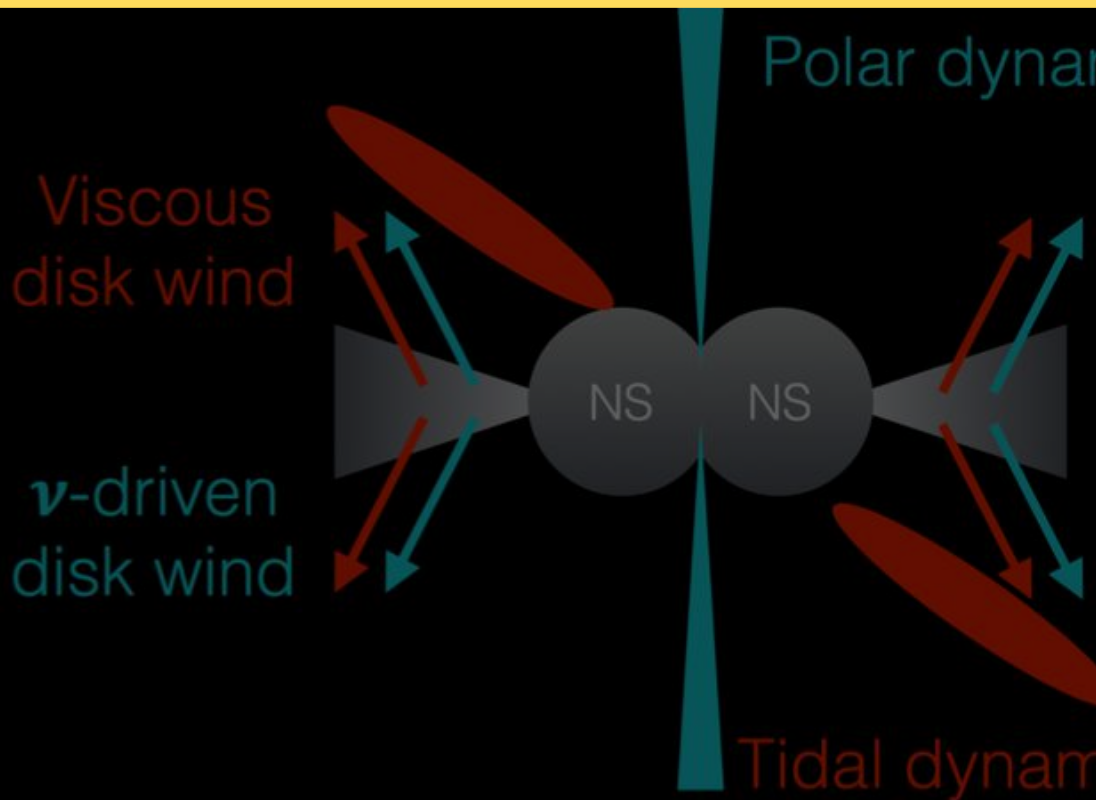
Red: low Y_e, neutron-rich, **heavy** 2nd+3rd peak r-process

Alex Ji

see e.g. Metzger 2017, poster by T. Tsujimoto

Slide from A. Ji's talk (Session 3)

NSMs should not make identical r-process yields



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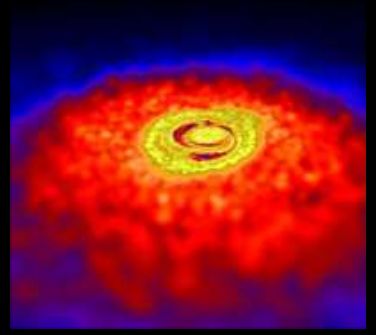
Alex Ji

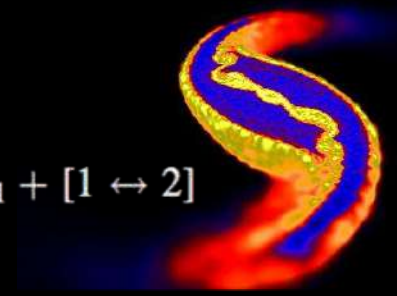
see e.g. Metzger 2017, poster by T. Tsujimoto

Slide from A. Ji's talk (Session3)

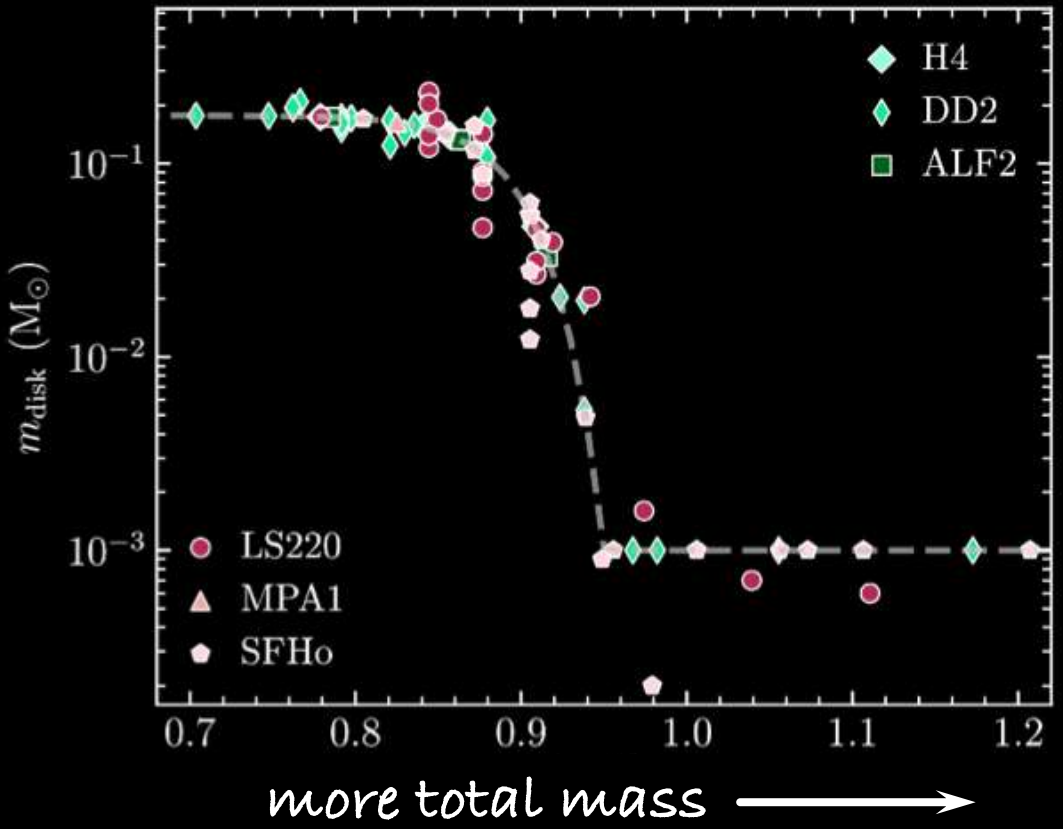
The mass ejected by the different outflow mechanisms **depend on the BNS properties**

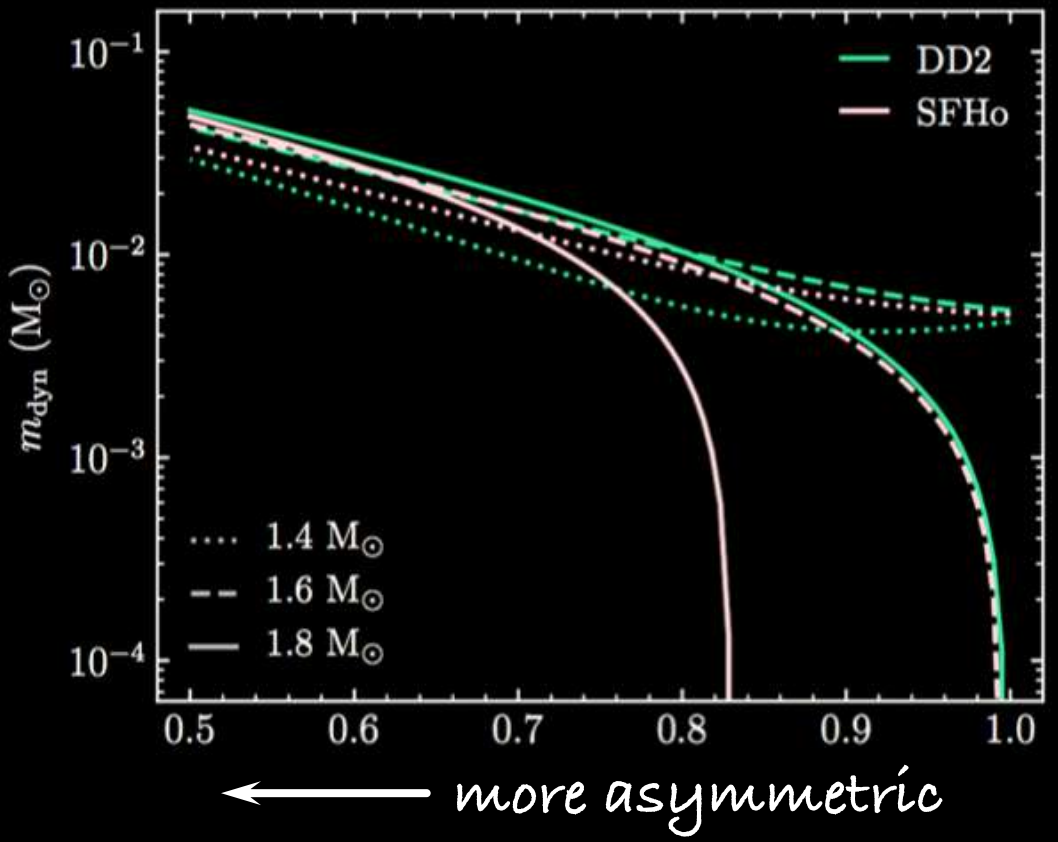


$$\log_{10}(m_{\rm disk}) = \max\left\{-3,\, a\left(1 + b\tanh\left[\frac{c - M_{\rm tot}/M_{\rm thr}}{d}\right]\right)\right\},$$



$$\frac{m_{\rm dyn}}{10^{-3}M_\odot} = \left[\frac{a}{\mathcal{C}_1} + b\left(\frac{M_2}{M_1}\right)^n + c\mathcal{C}_1\right]M_1 + [1 \leftrightarrow 2]$$

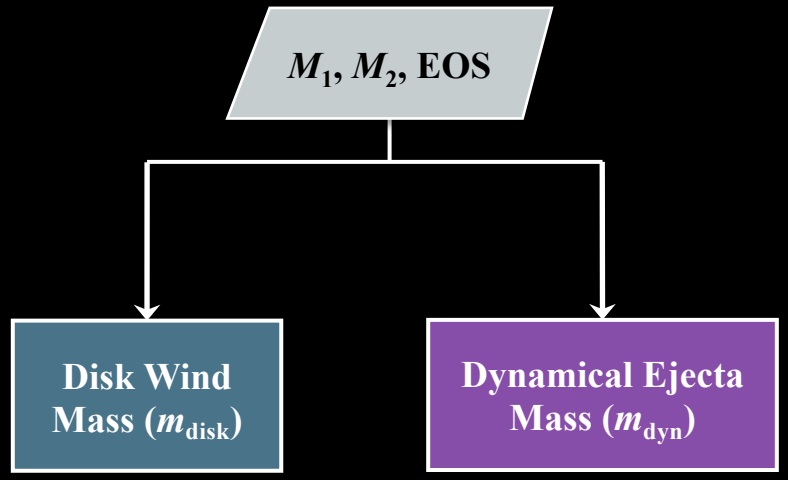




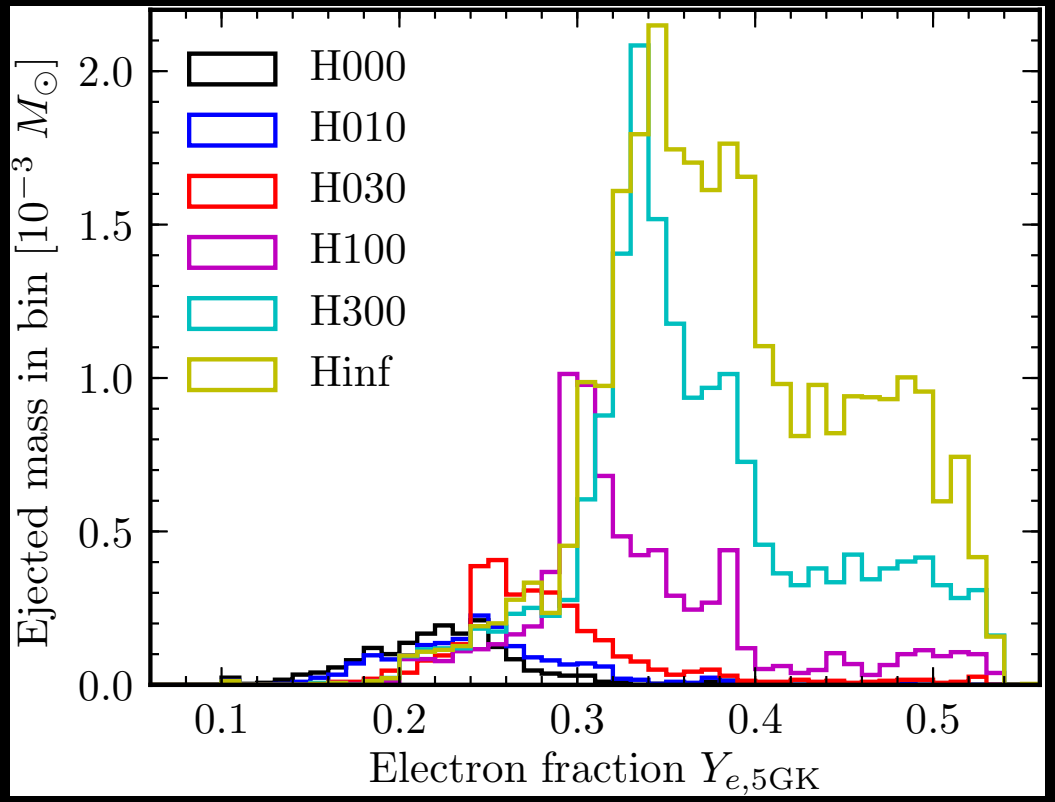
EMH+ (2021)

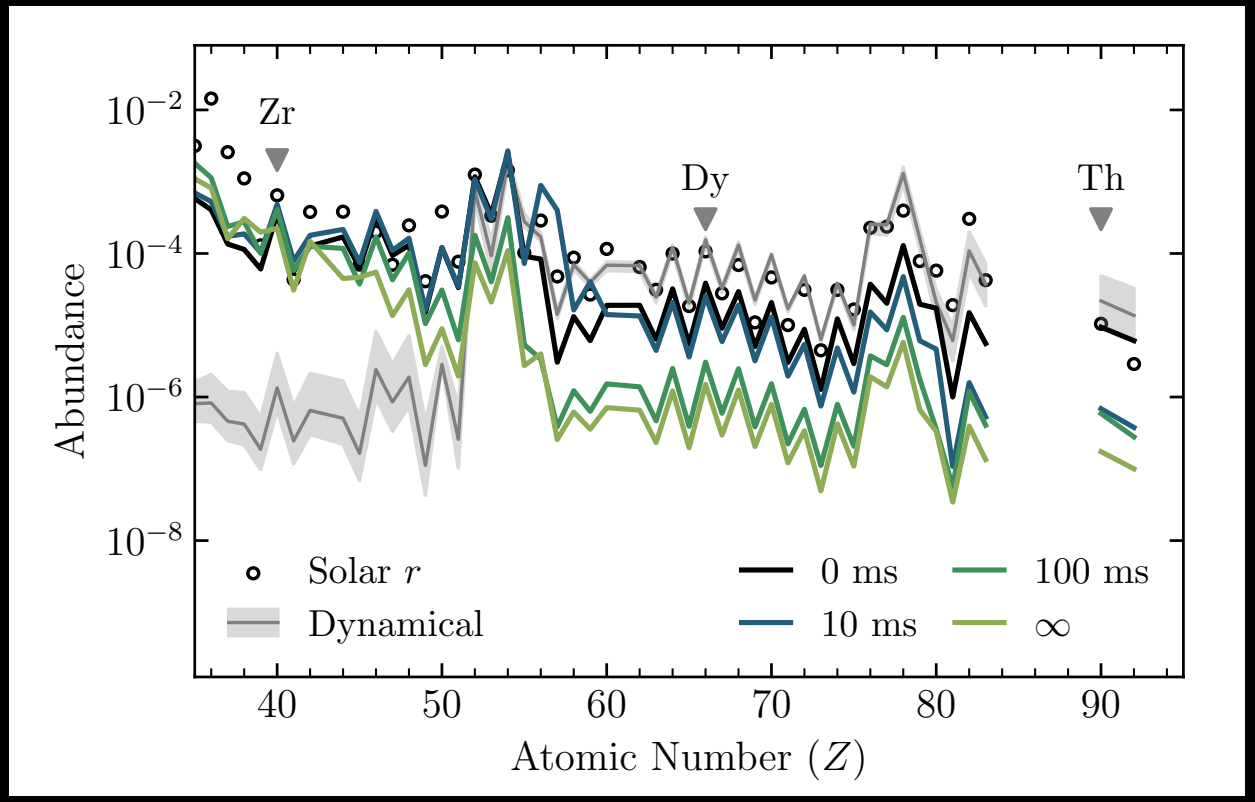
See also: Radice+ (2018), Dietrich+ (2020), Krueger & Foucart (2020)

From a selection of M_1, M_2, and EOS, we can find the total mass ejected by the two components



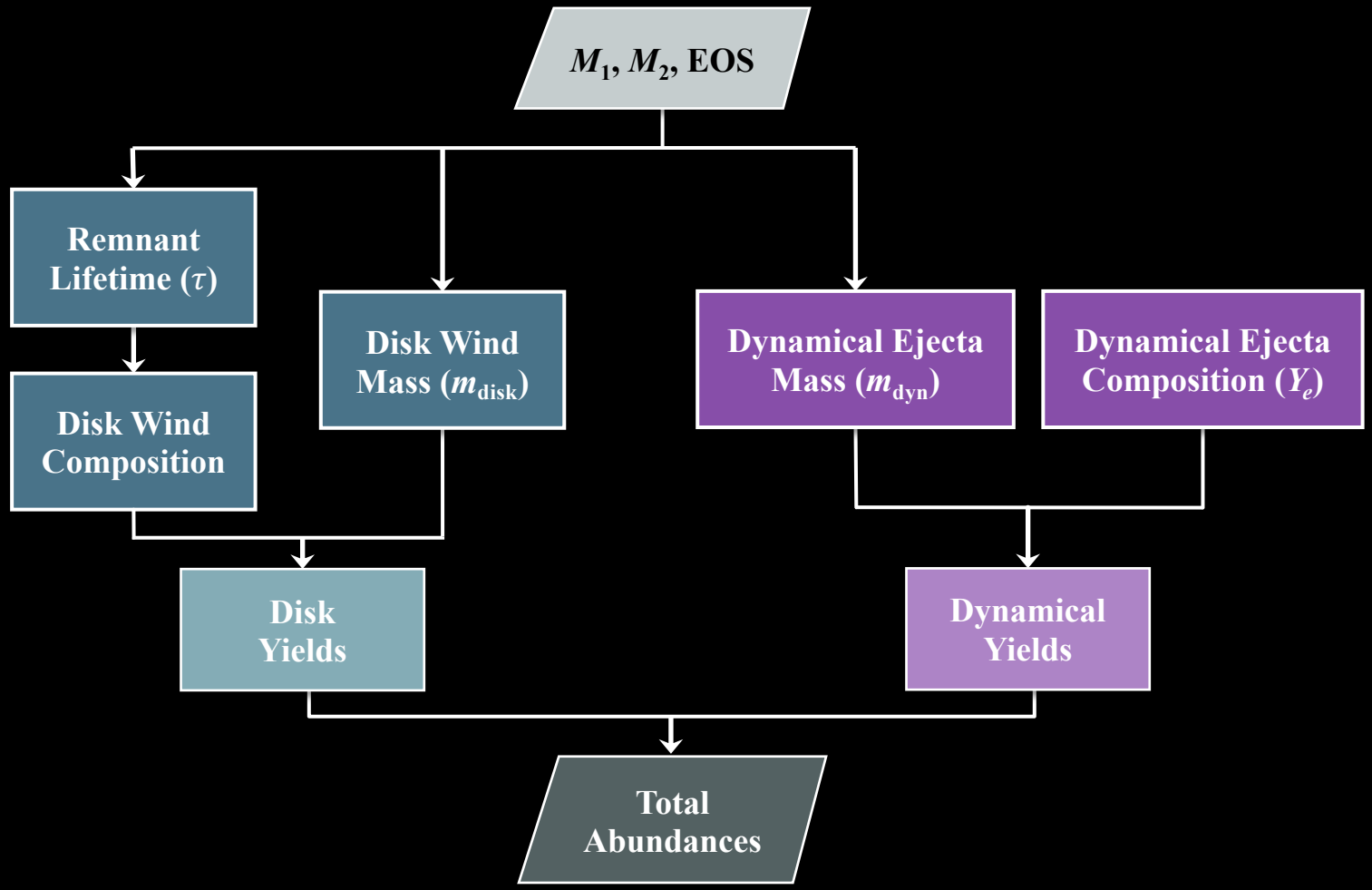
The **elemental composition** of the ejecta also depend on the binary properties

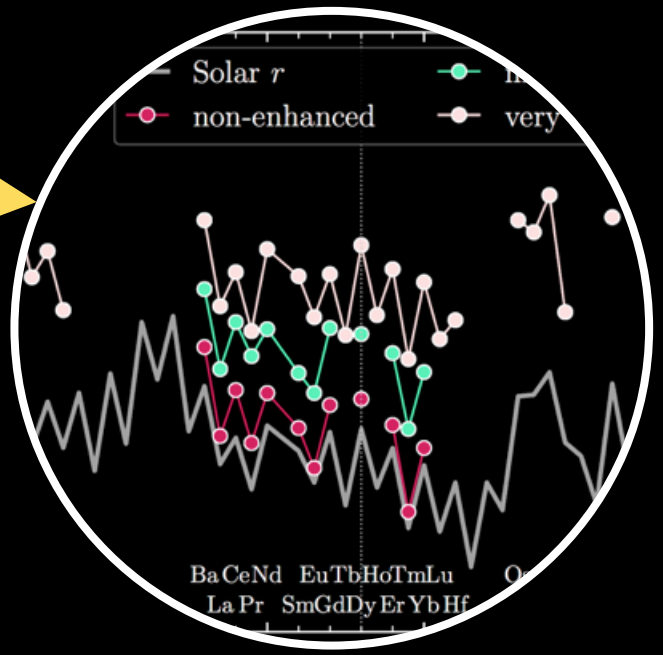




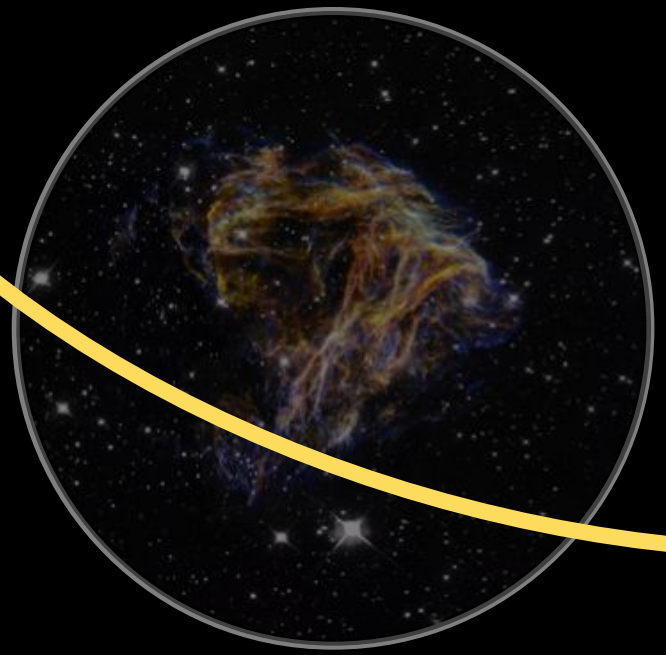
Lippuner+ (2017); **EMH+** (2021)

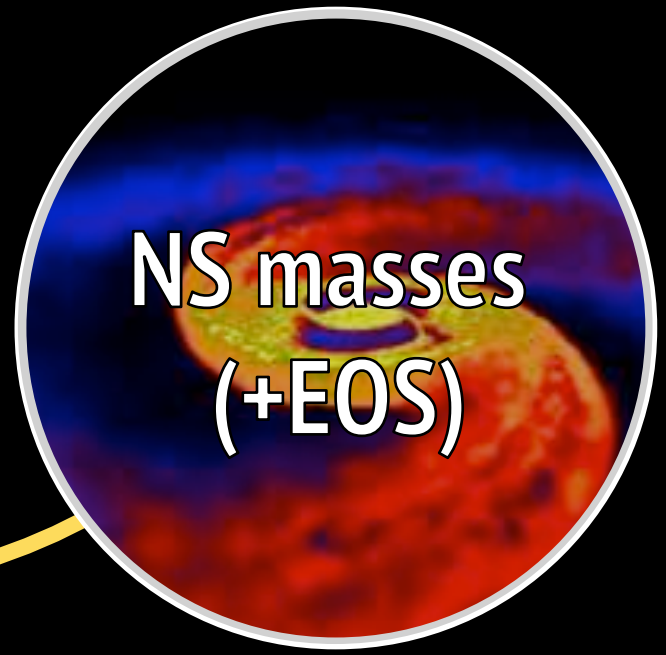
From a selection of M_1, M_2, and EOS, we can find the total *r*-process yields from an NSM event

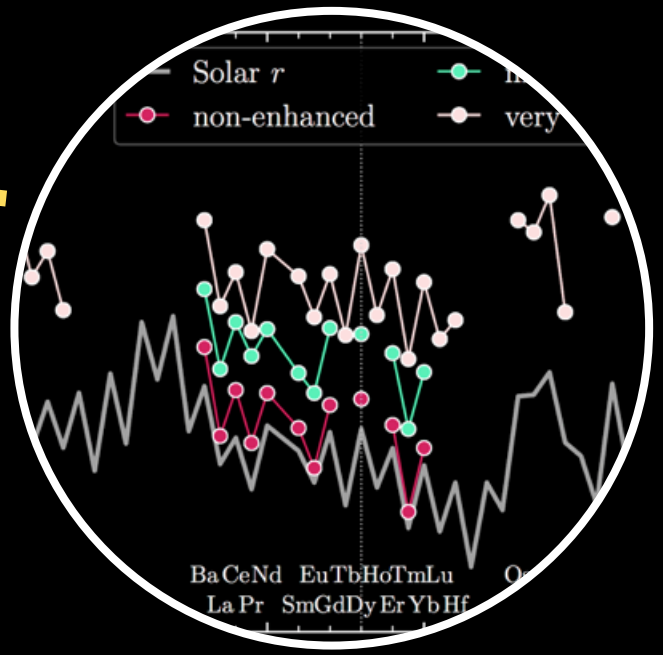




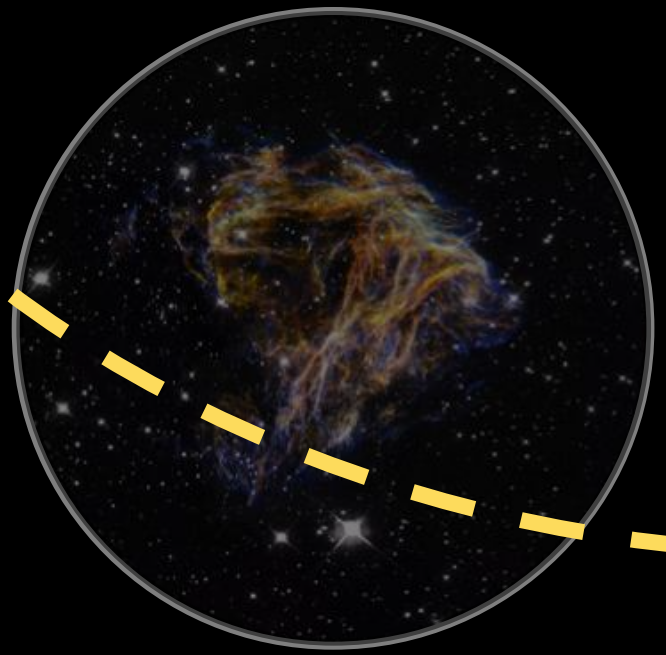
Stars with *r*-process signatures

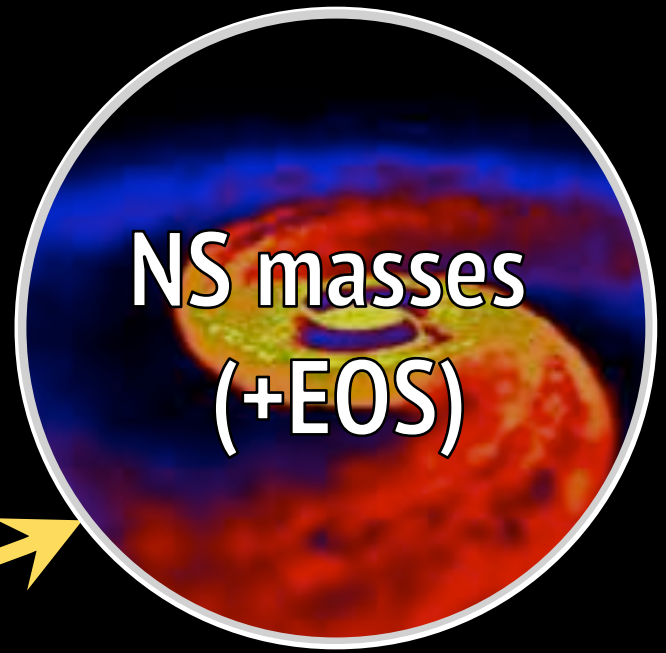


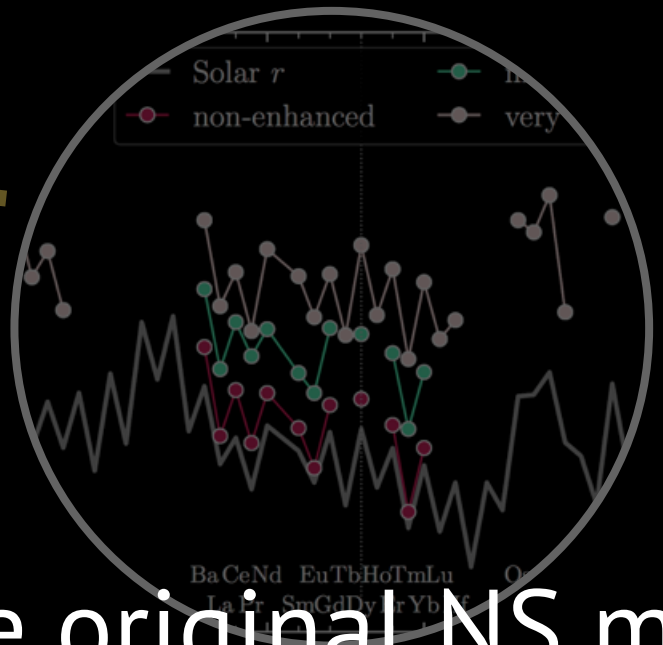




Stars with *r*-process signatures

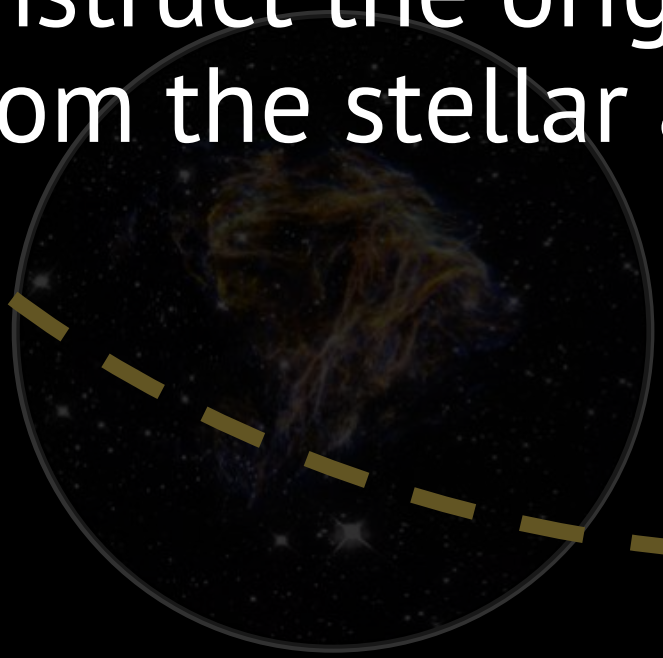


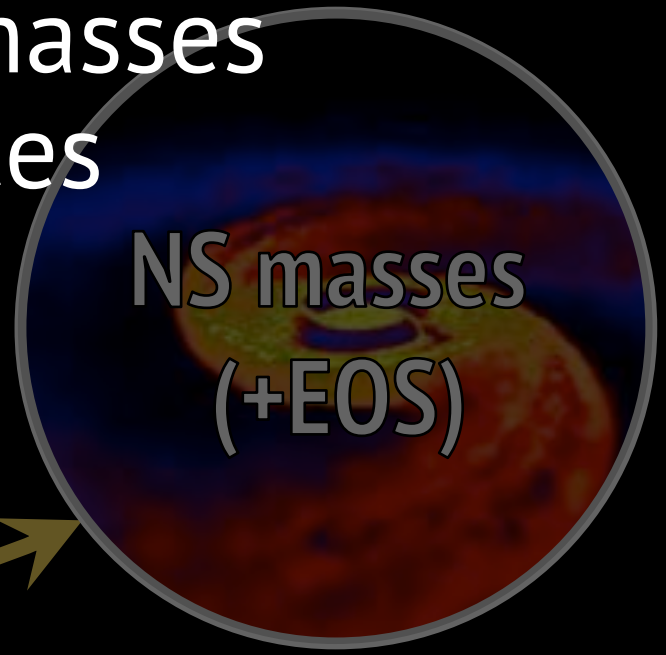




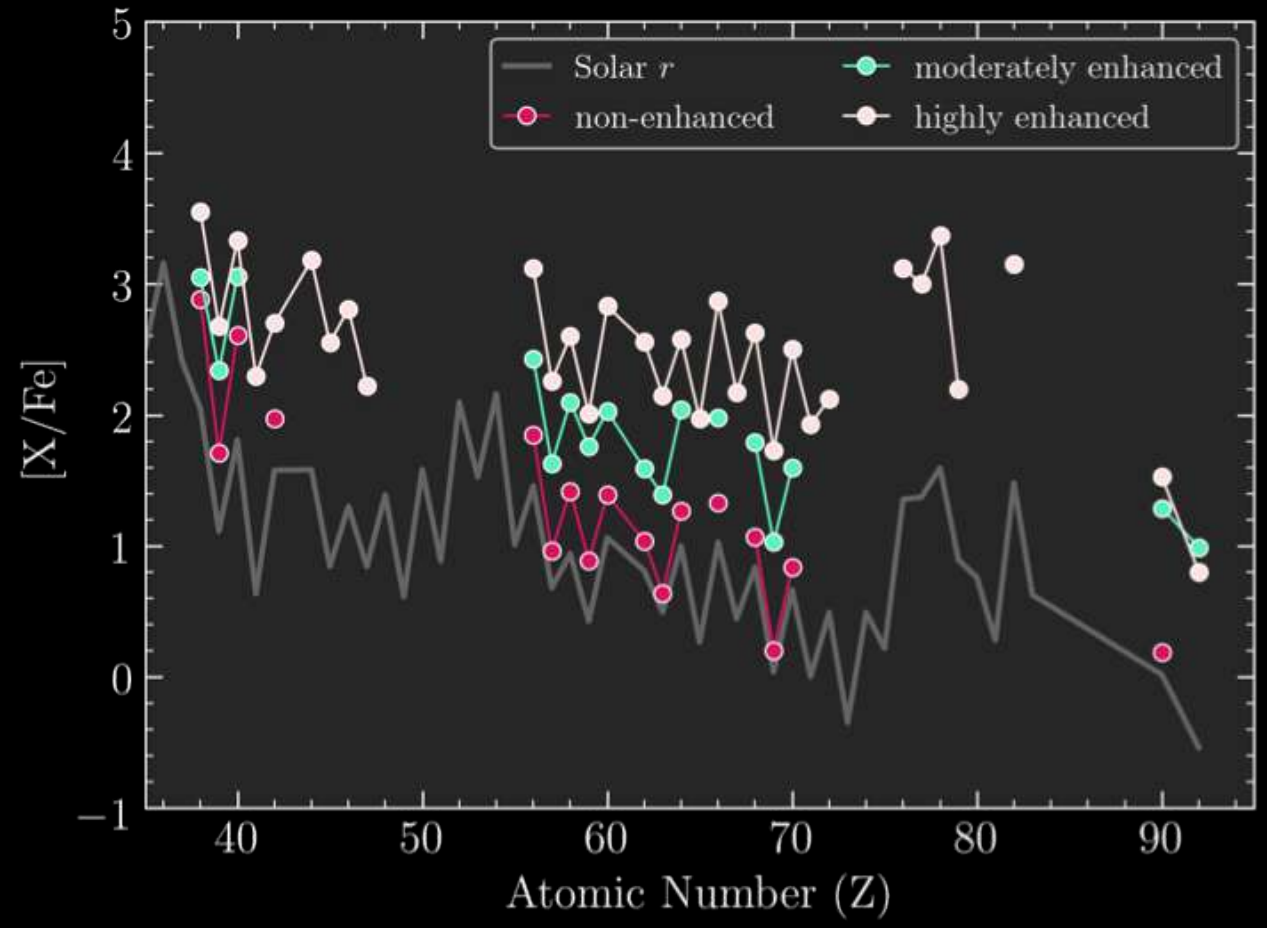
Stars with *r*-process signatures

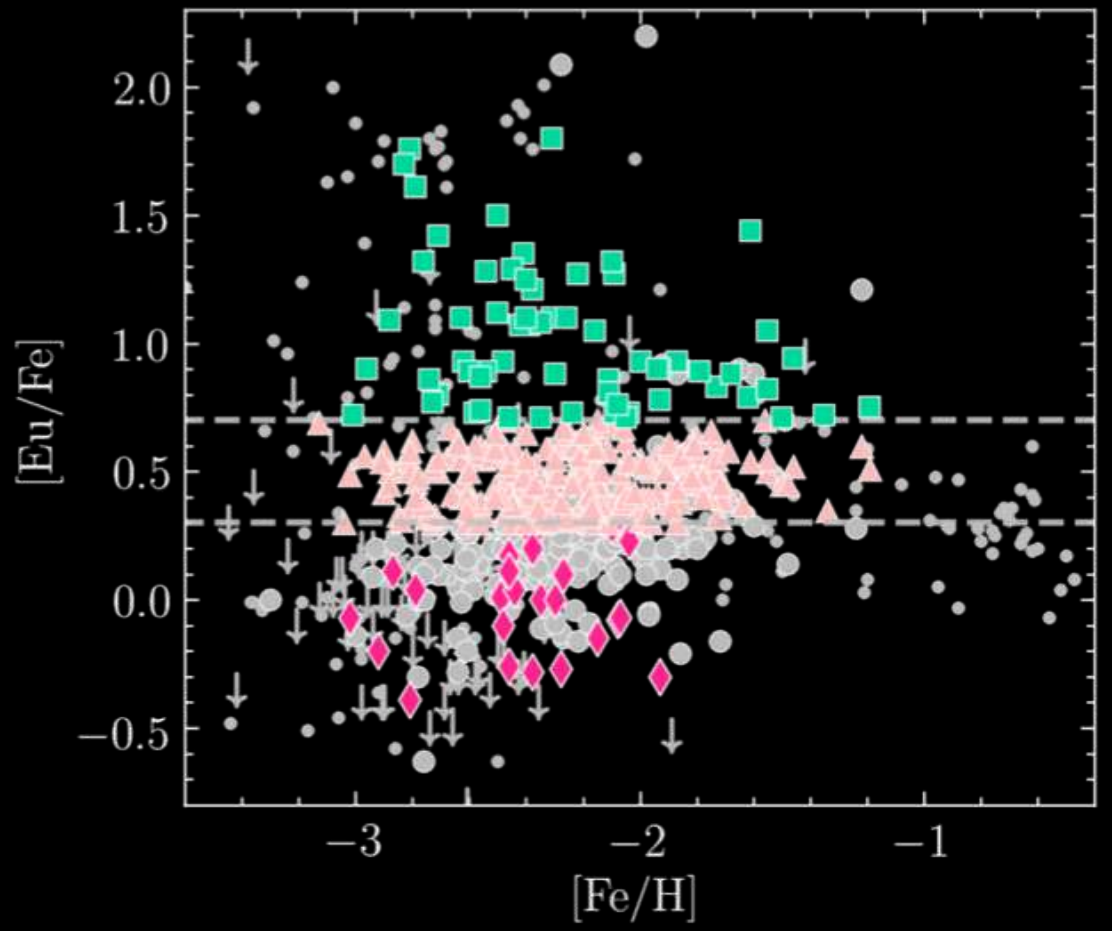
Reconstruct the original NS masses from the stellar abundances





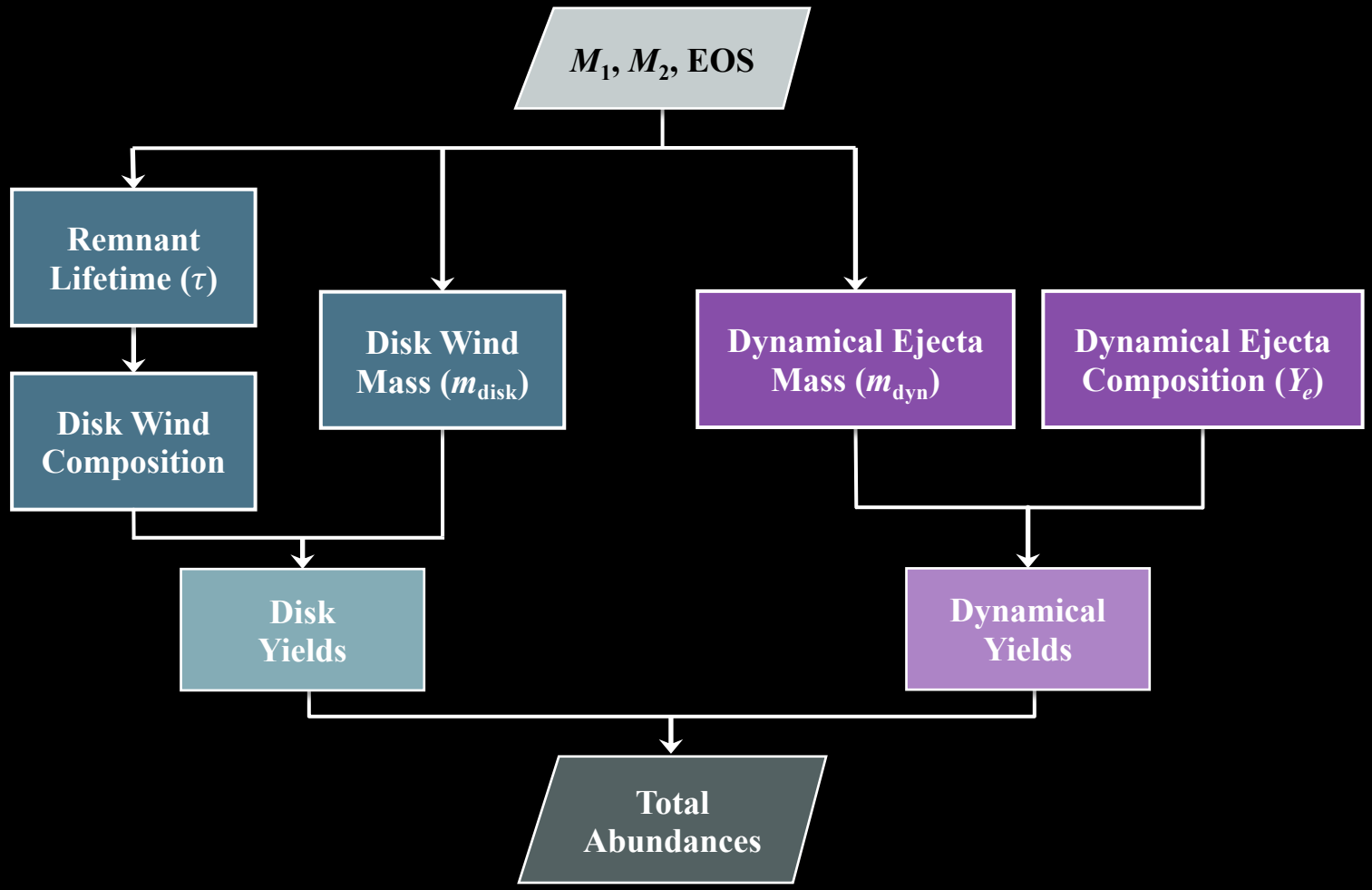
We need to consider the “non-enhanced” stars too





from Roederer+ (2014), Honda+ (2004), Sneden+ (2003)

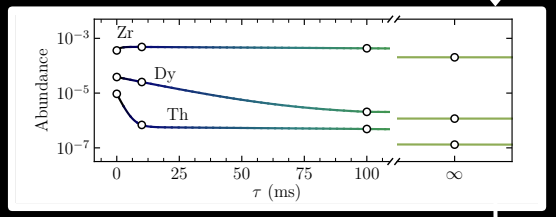
From a selection of M_1, M_2, and EOS, we can find the total *r*-process yields from an NSM event



From a selection of M_1, M_2, and EOS, we can find the total *r*-process yields from an NSM event

M_1, M_2, EOS

$$\log_{10}(\tau) = e_0 + e_1 \log_{10}\left(\frac{\sqrt{M_1 M_2}}{M_{\rm TOV}}\right)$$



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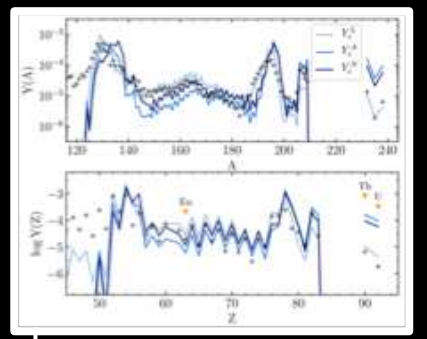
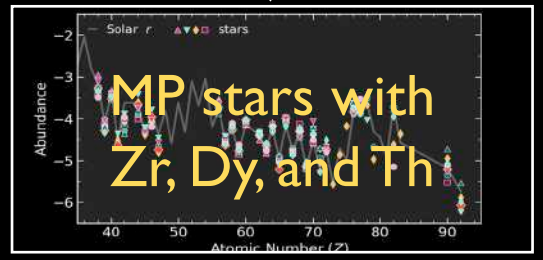
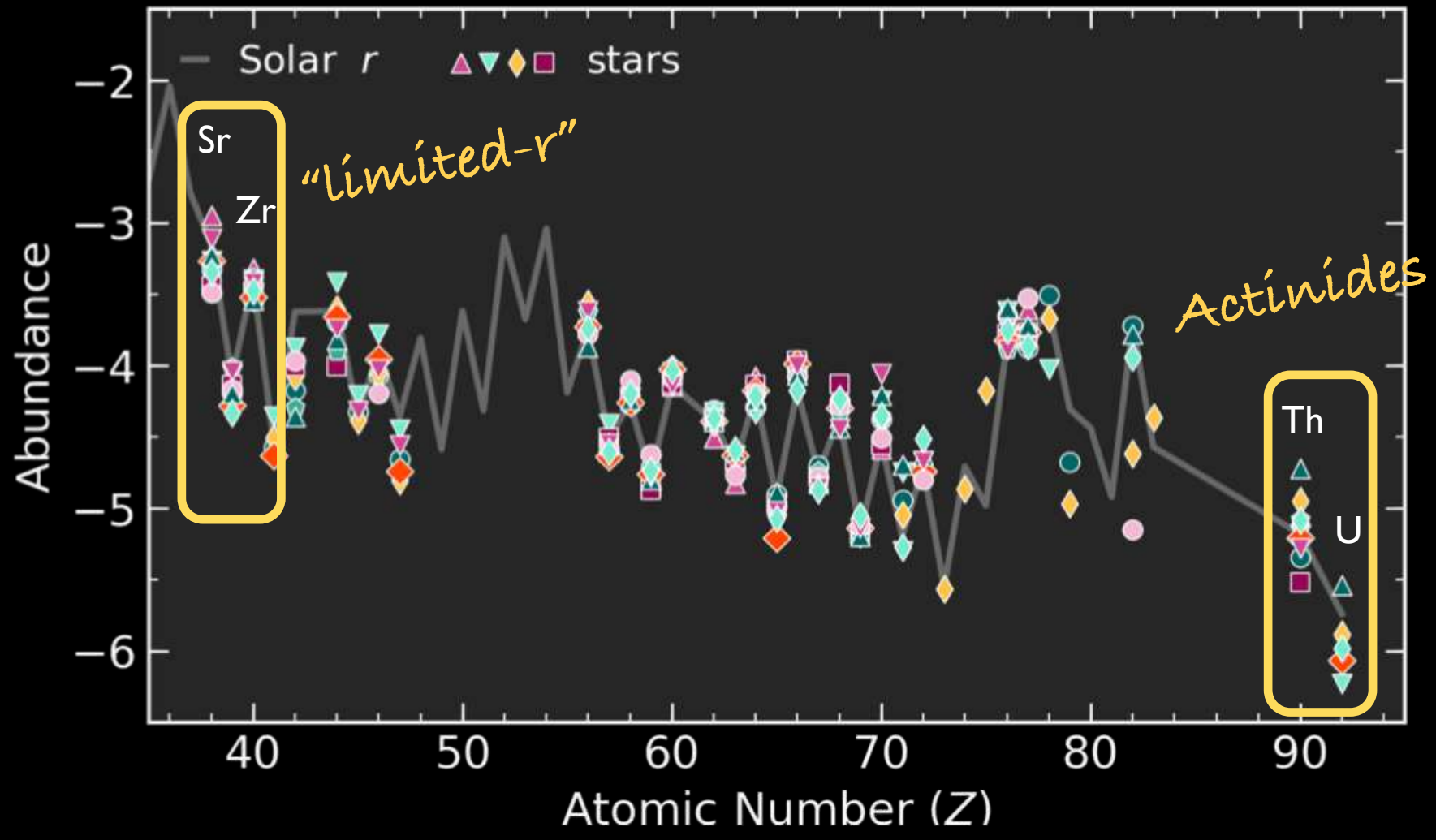
$$\frac{m_{\rm dyn}}{10^{-3}{\rm M}_\odot} = \left[\frac{a}{\mathcal{C}_1} + b\left(\frac{M_2}{M_1}\right)^n + c\mathcal{C}_1\right] M_1 + [1 \leftrightarrow 2]$$



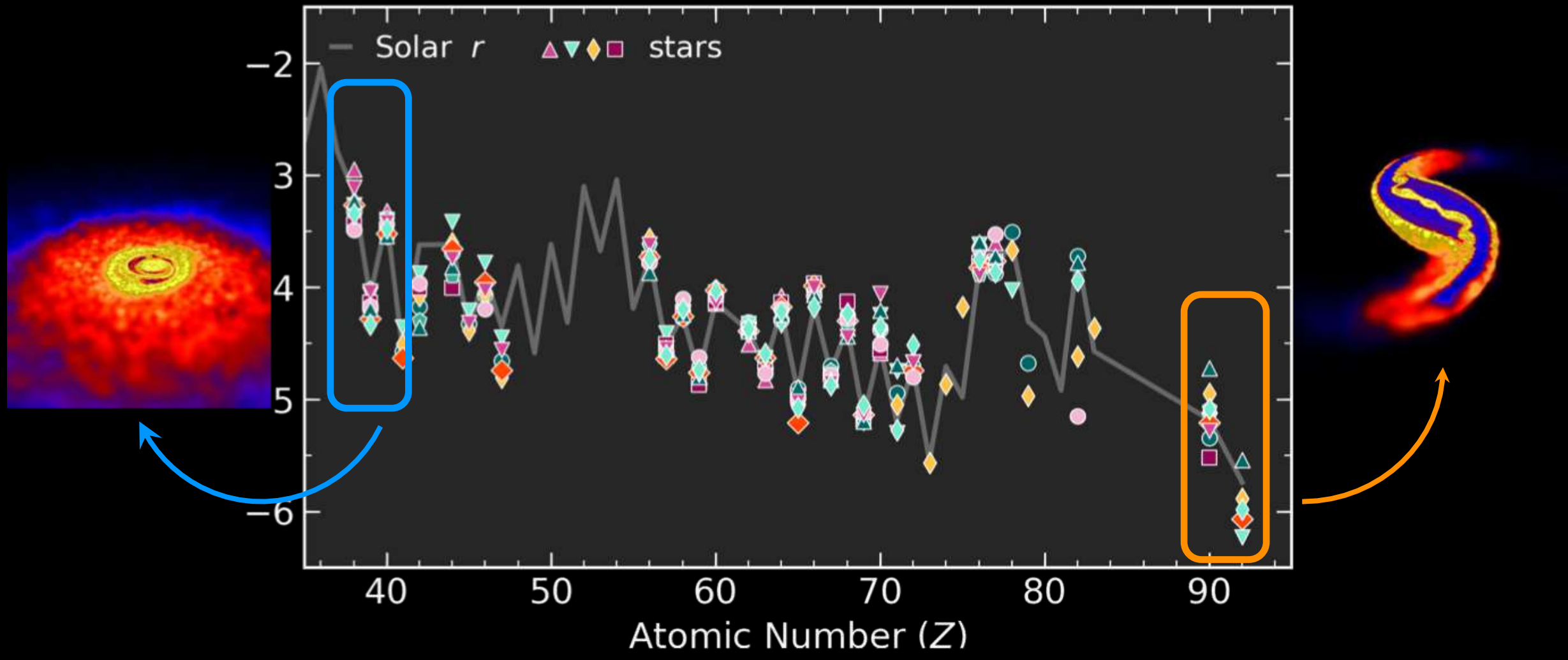


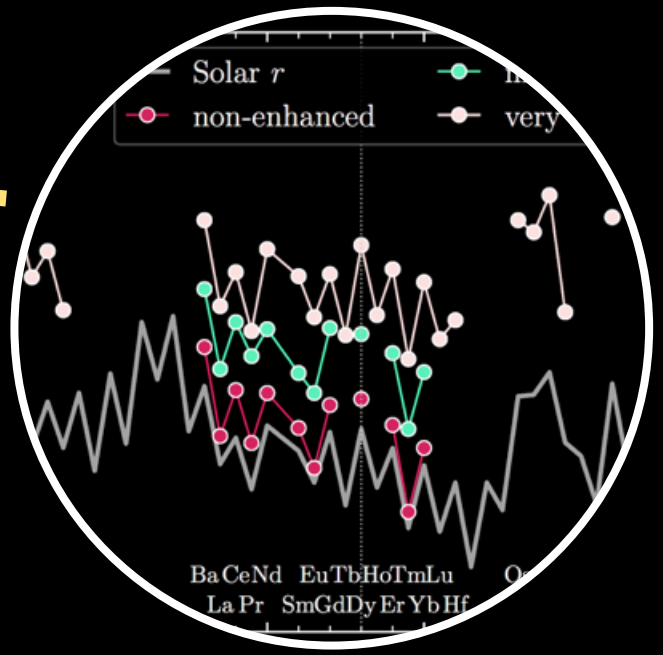
MP stars with Zr, Dy, and Th

Elemental patterns of the *r*-stars differ in the **lightest** and **heaviest** elements



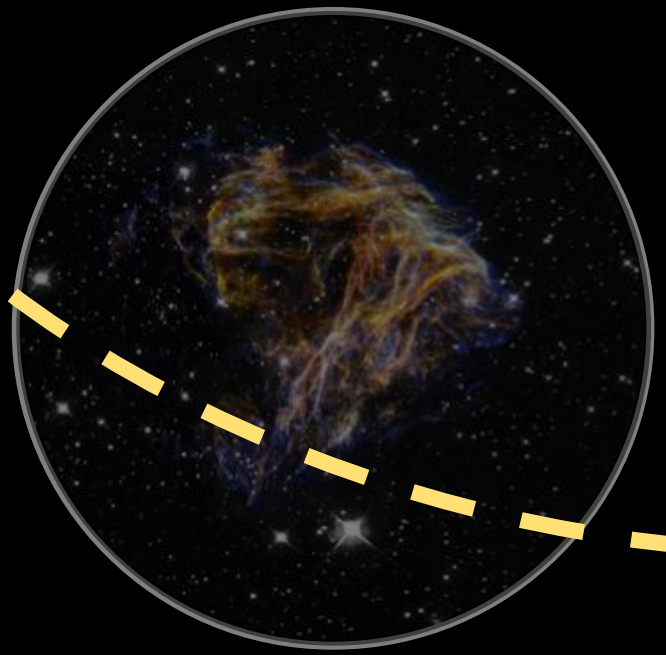
These are the regions where differences in NS binaries manifest

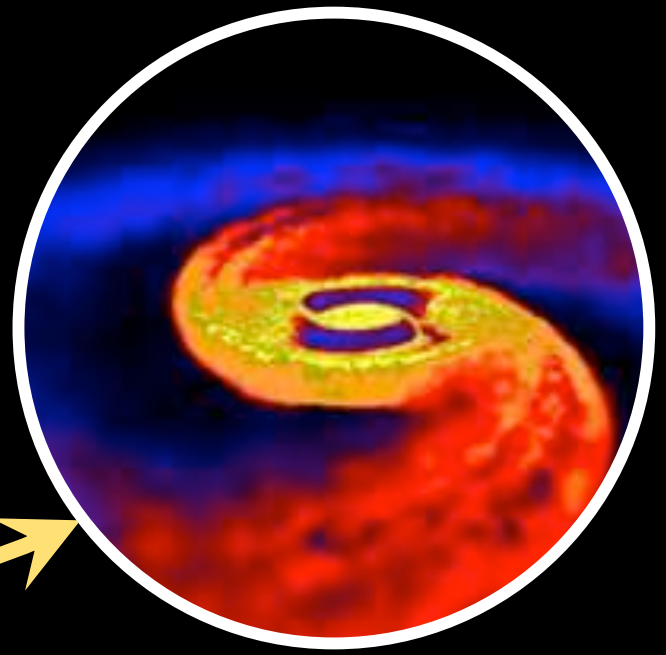




Stars with *r*-process signatures

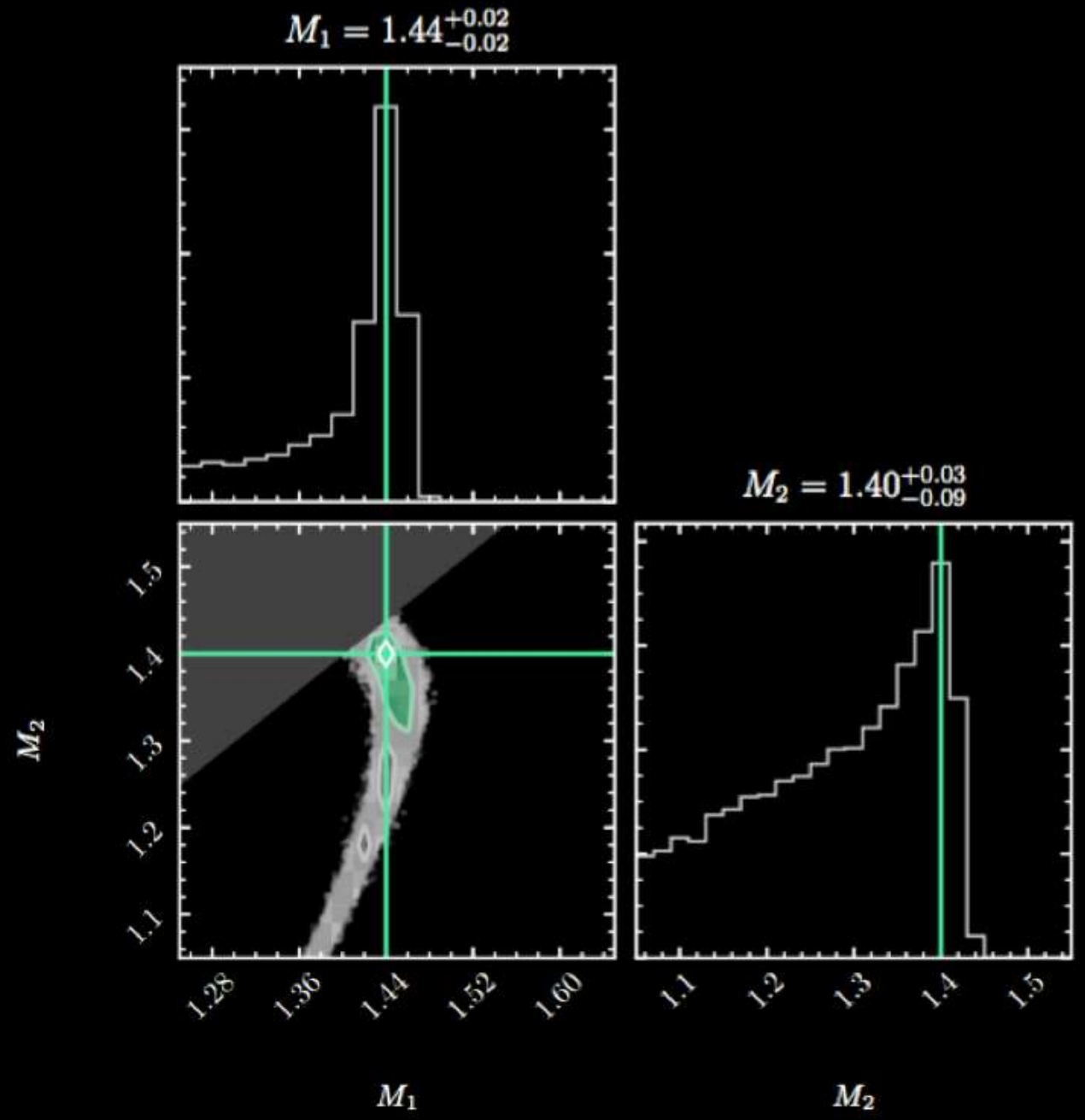
MCMC

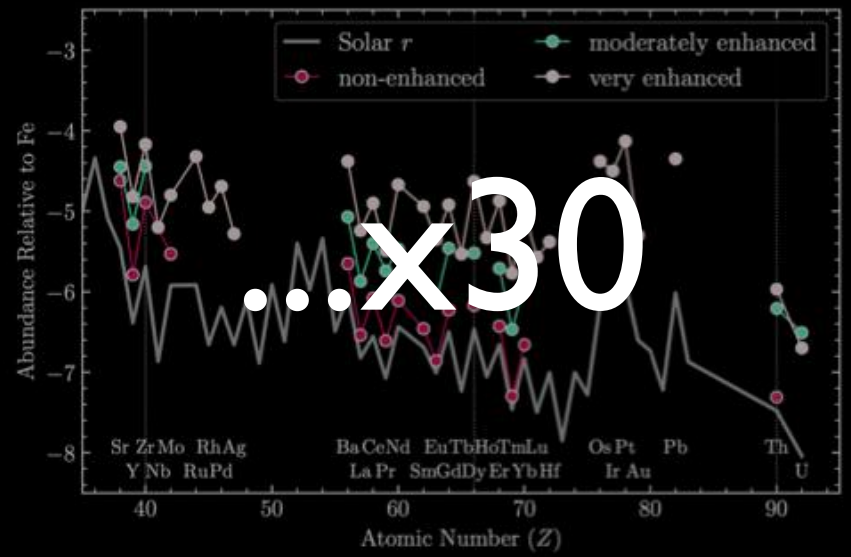




NS masses

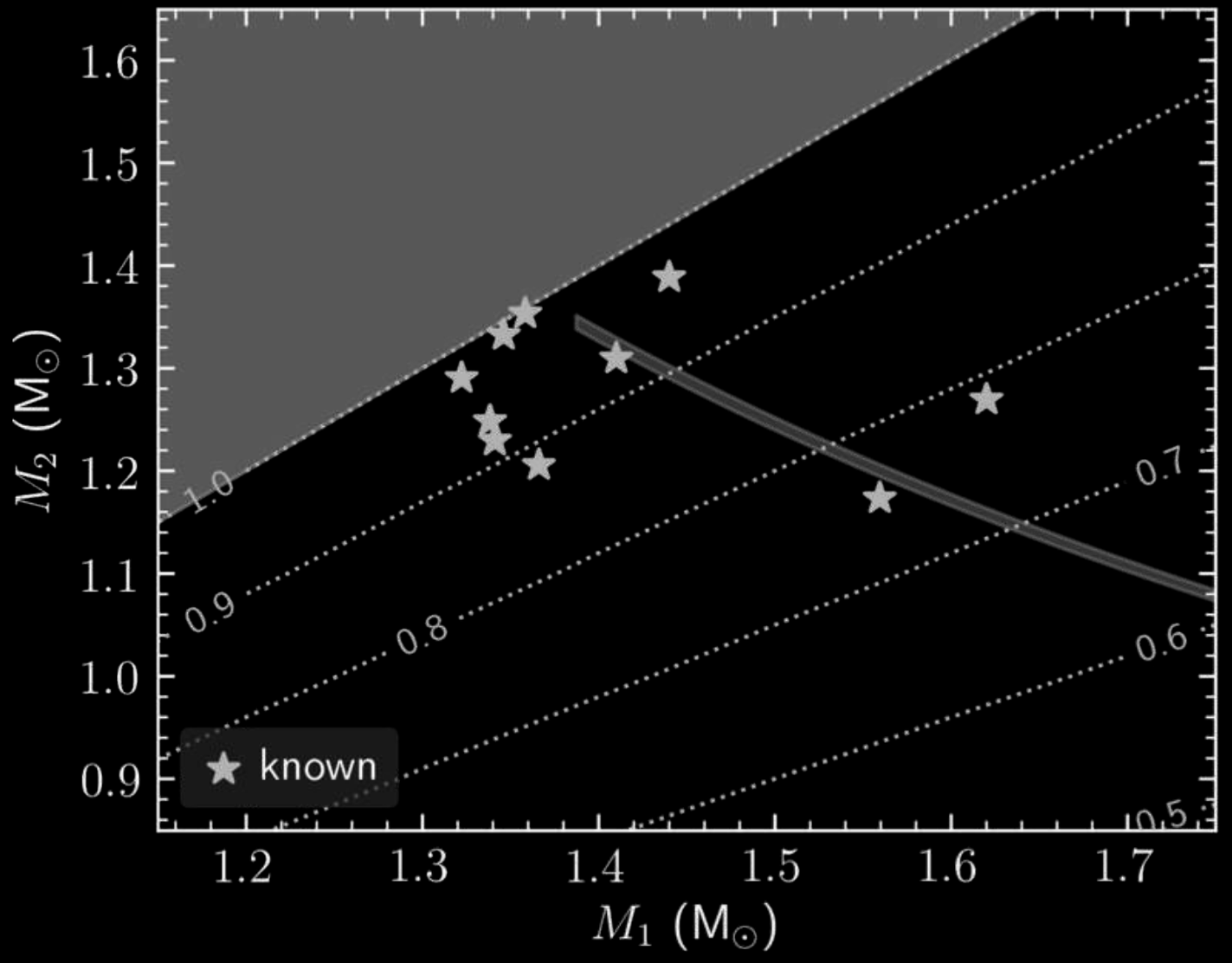
Use an MCMC method to explore the M_1-M_2 parameter space



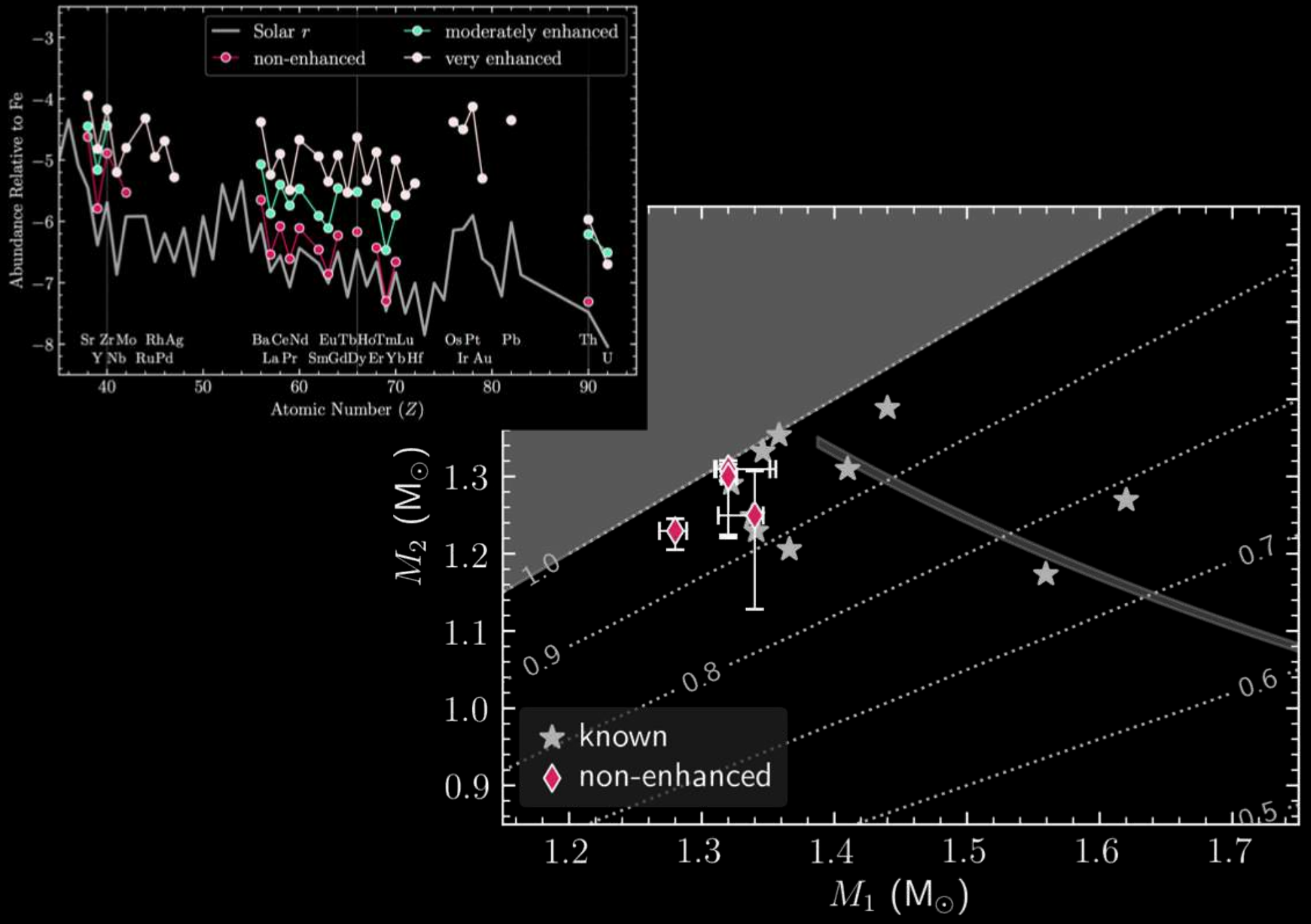


...x30

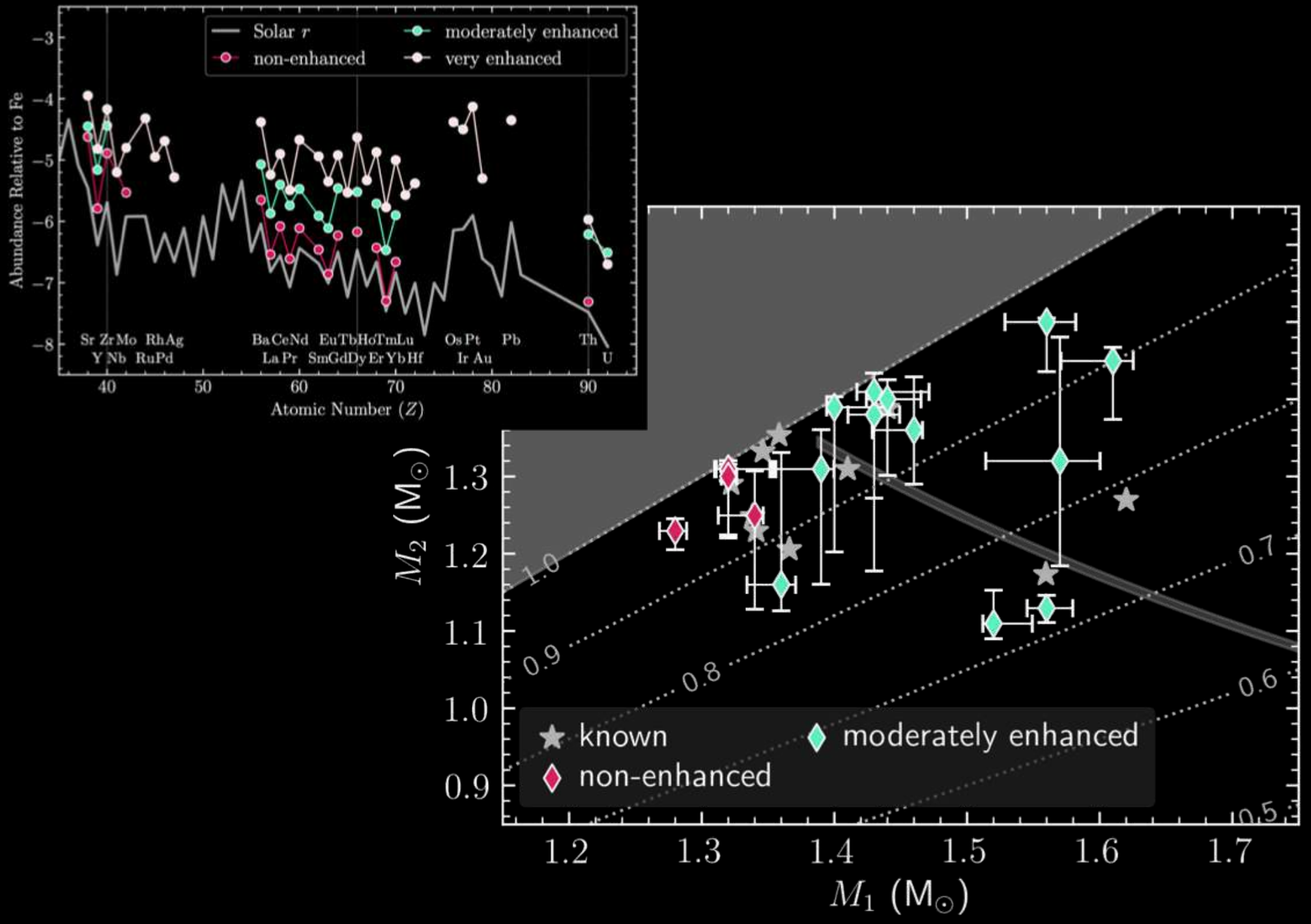
EMH+ (2021)


1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
M_2 ($M_\odot$)
1.0
0.9
0.8
0.7
0.6
0.5
known
1.2
1.3
1.4
1.5
1.6
1.7
M_1 ($M_\odot$)

EMH+ (2021)


Solar r
non-enhanced
moderately enhanced
very enhanced
Abundance Relative to Fe
Sr Zr Mo Rh Ag
Y Nb Ru Pd
Ba Ce Nd Eu Tb Ho Tm Lu
La Pr Sm Gd Dy Er Yb Hf
Os Pt Pb
Ir Au
Th
U
Atomic Number (Z)
M_2 ($M_\odot$)
M_1 ($M_\odot$)
1.0
0.9
0.8
0.7
0.6
0.5
known
non-enhanced

EMH+ (2021)


Solar r
non-enhanced
moderately enhanced
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Atomic Number (Z)
Sr Zr Mo Rh Ag
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Os Pt Pb
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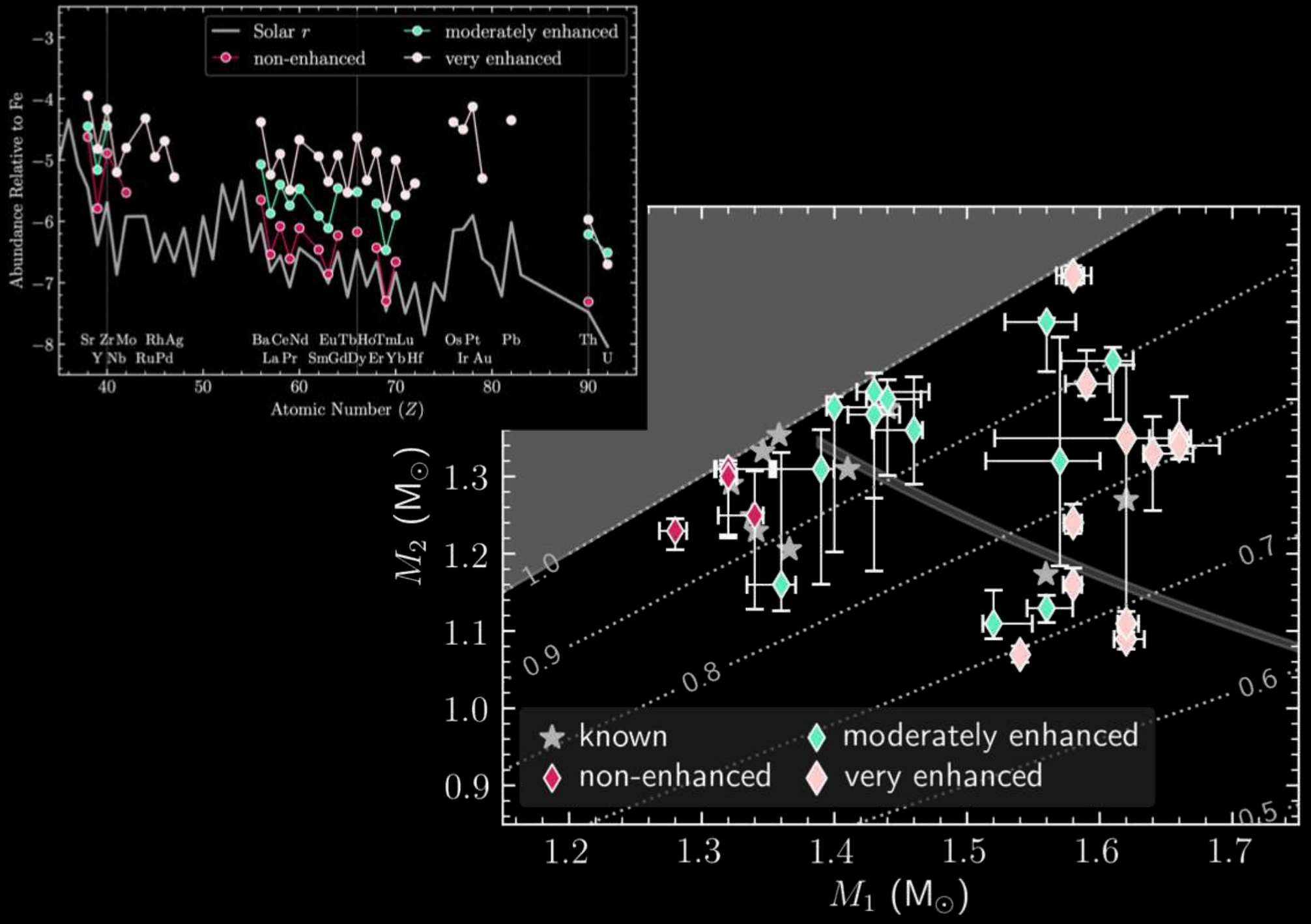
Th
U
known
non-enhanced
moderately enhanced
M_2 ($M_\odot$)
M_1 ($M_\odot$)
1.0
0.9
0.8
0.7
0.6
0.5

EMH+ (2021)


Solar r
non-enhanced
moderately enhanced
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Abundance Relative to Fe
Atomic Number (Z)
Sr Zr Mo Rh Ag
Y Nb Ru Pd
Ba Ce Nd Eu Tb Ho Tm Lu
La Pr Sm Gd Dy Er Yb Hf
Os Pt Pb
Ir Au
Th
U
M_2 ($M_\odot$)
M_1 ($M_\odot$)
1.0
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known
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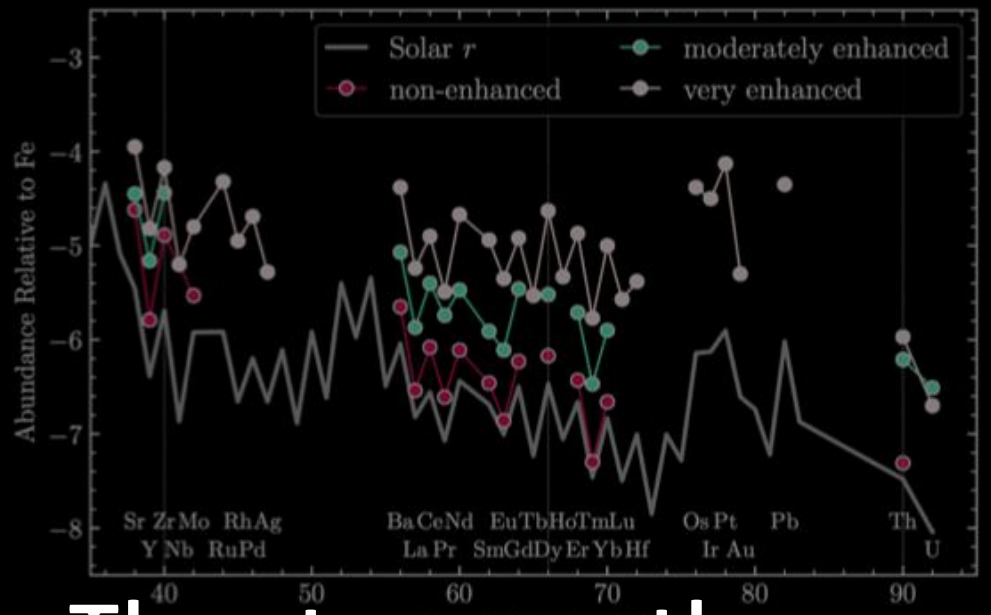
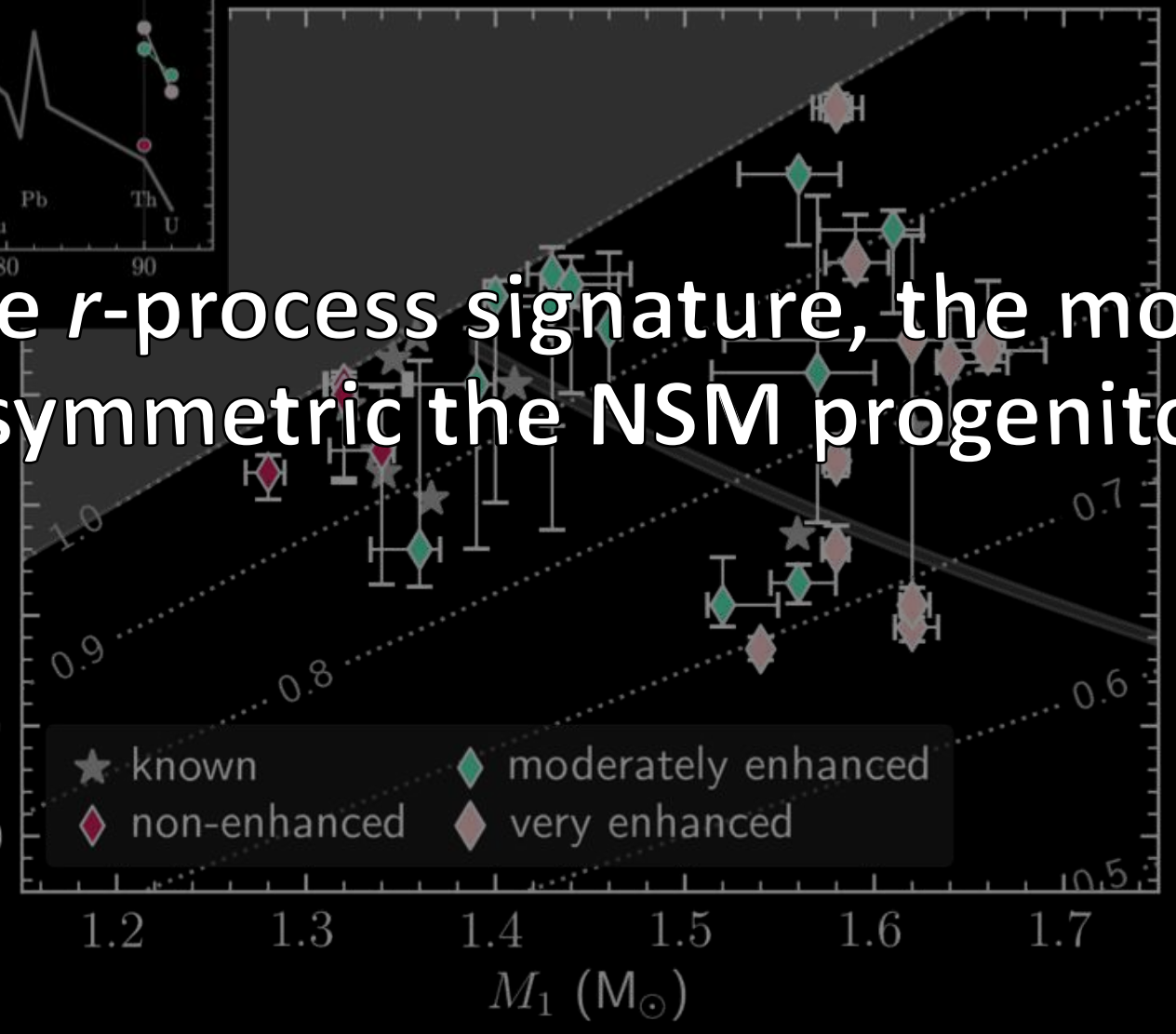
EMH+ (2021)

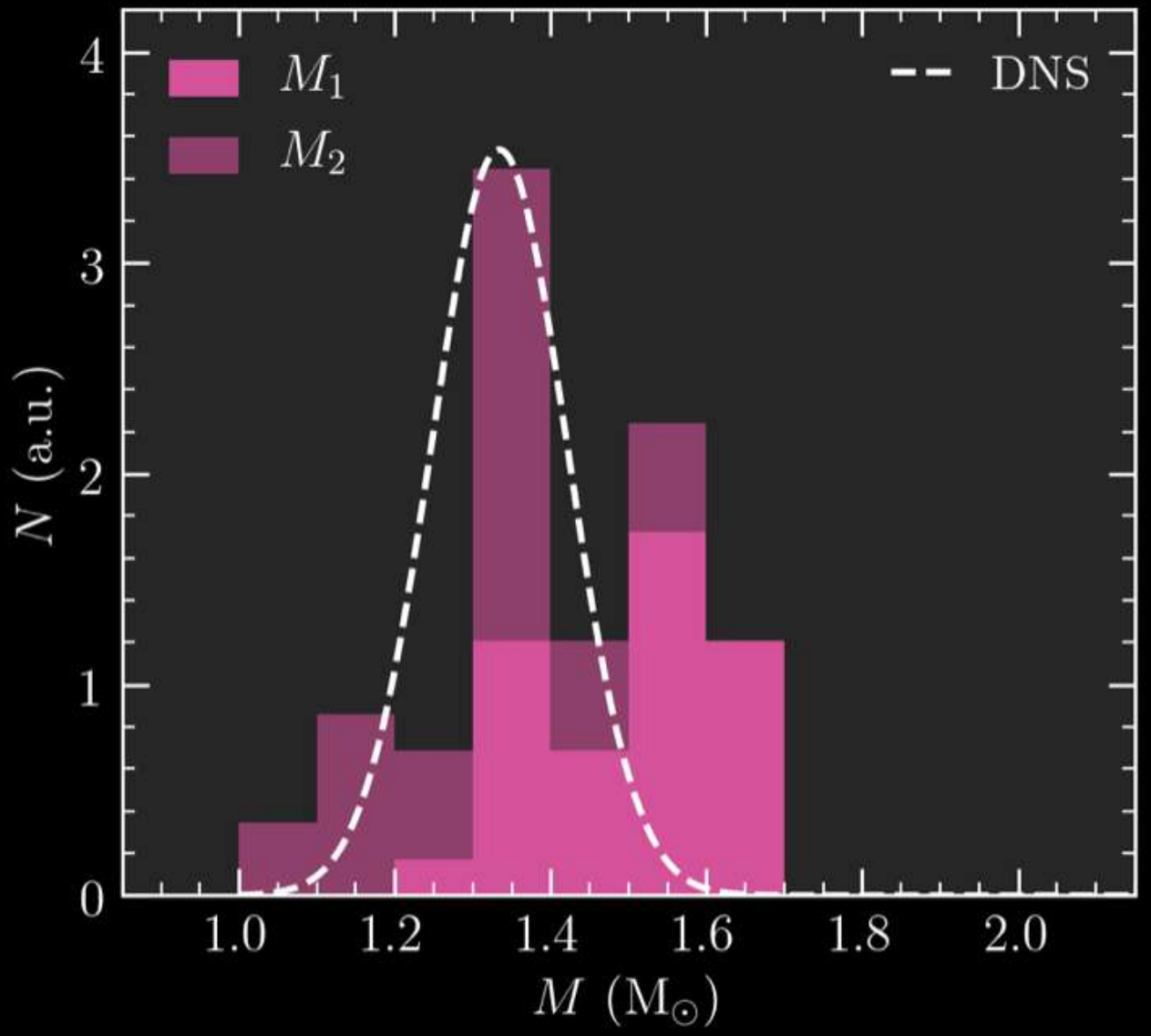


The stronger the *r*-process signature, the more massive and asymmetric the NSM progenitor



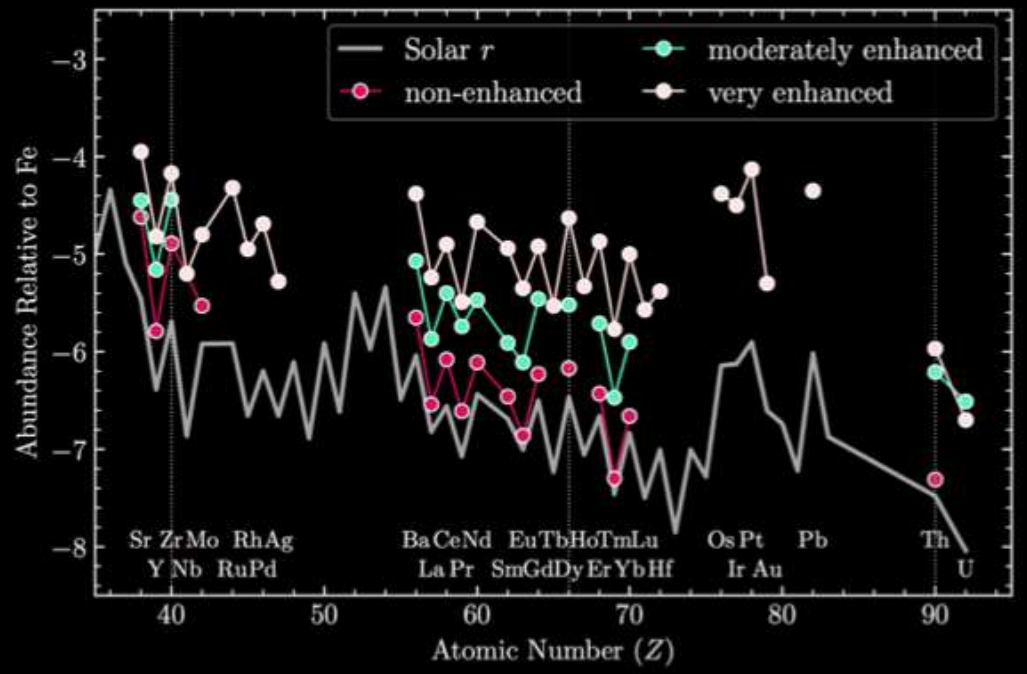
EMH+ (2021)

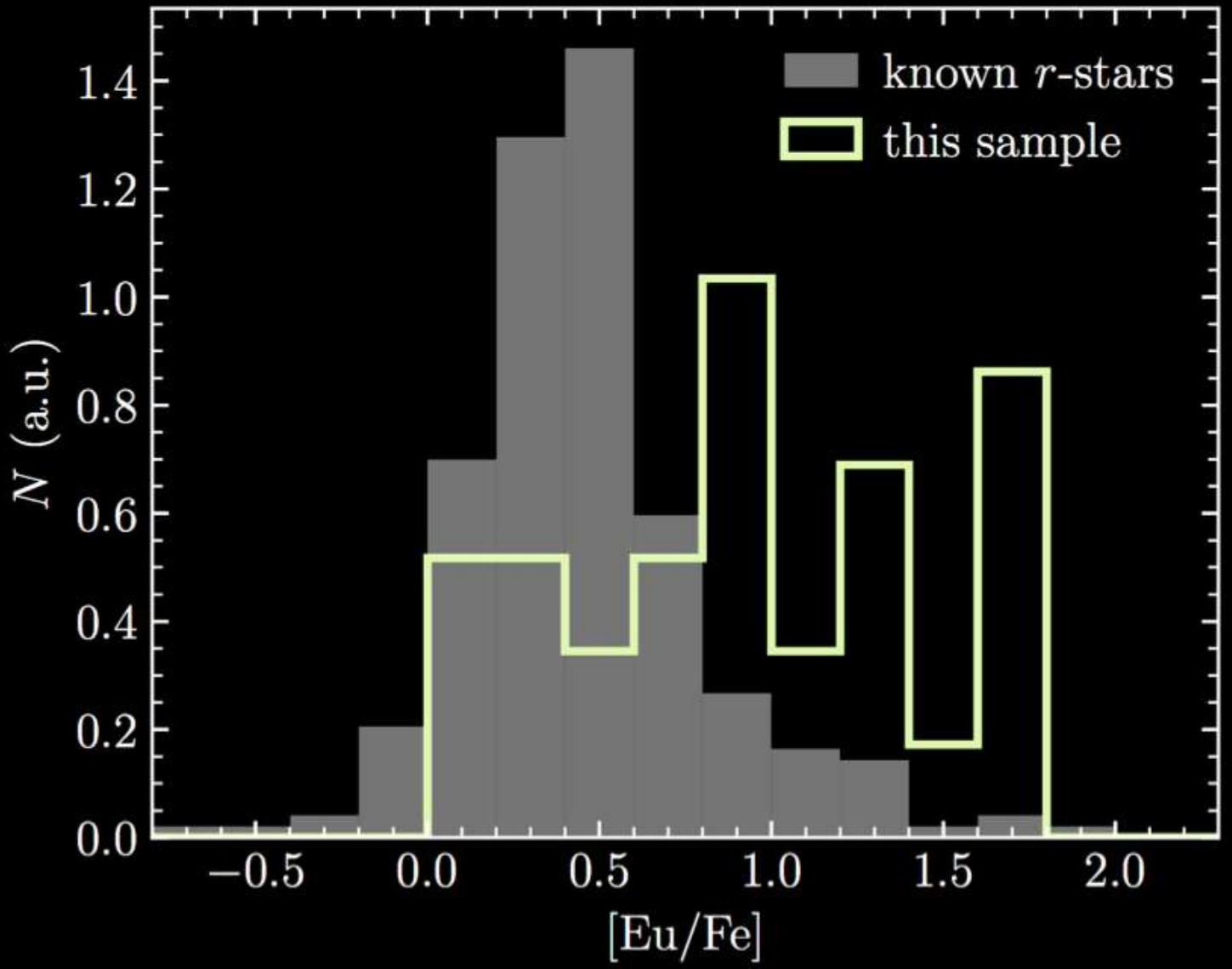
Results require more **higher-mass** DNS systems than are currently found in the Milky Way



EMH+ (2021)

The ~30 stars in our sample are already **more enhanced** than typical *r*-stars





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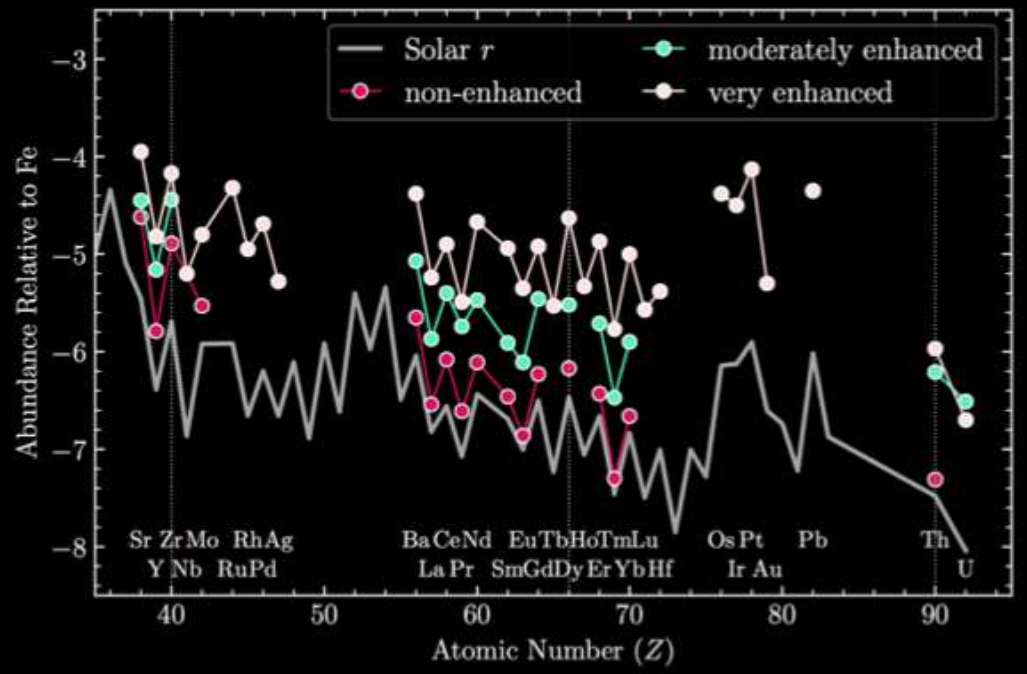
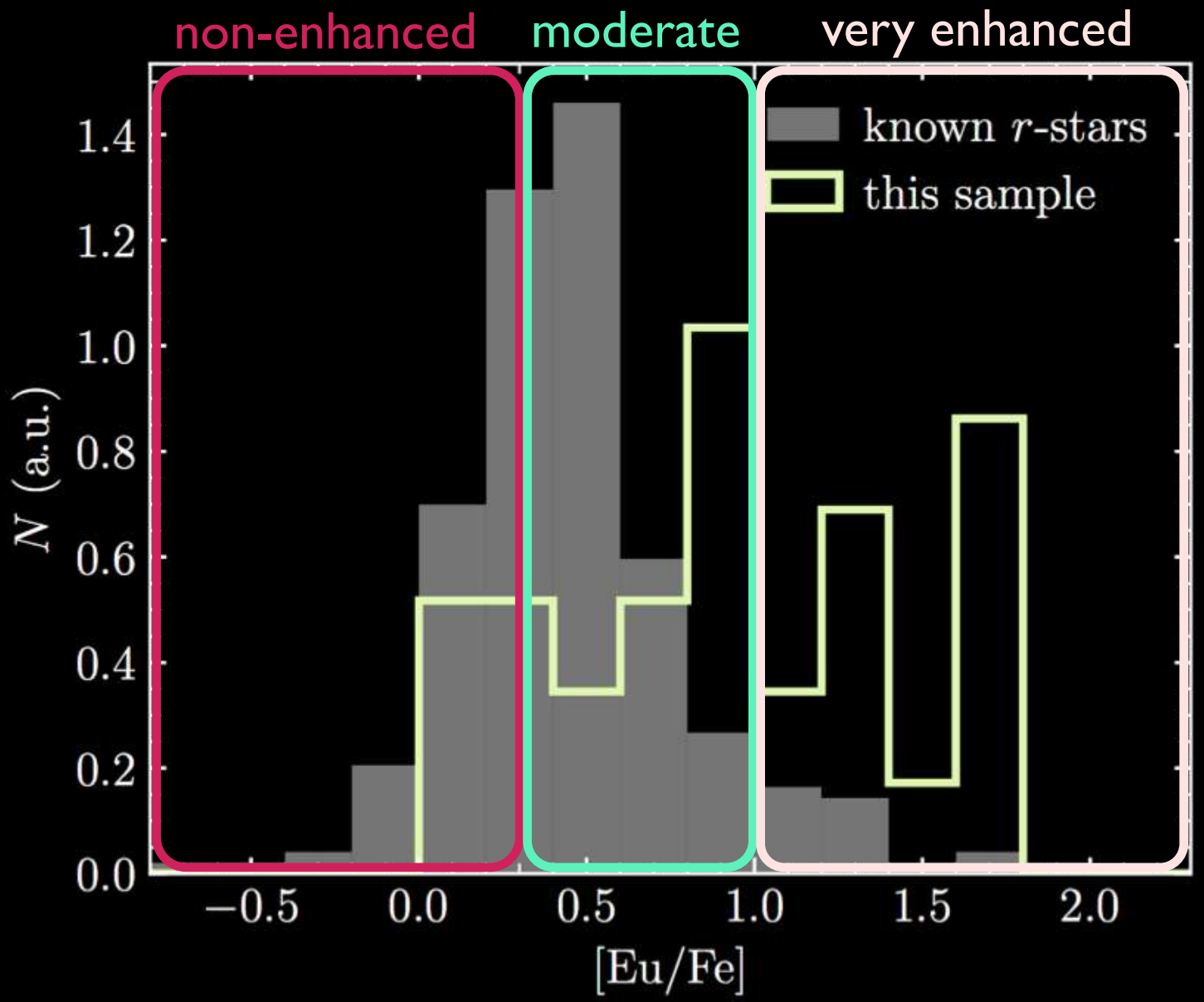
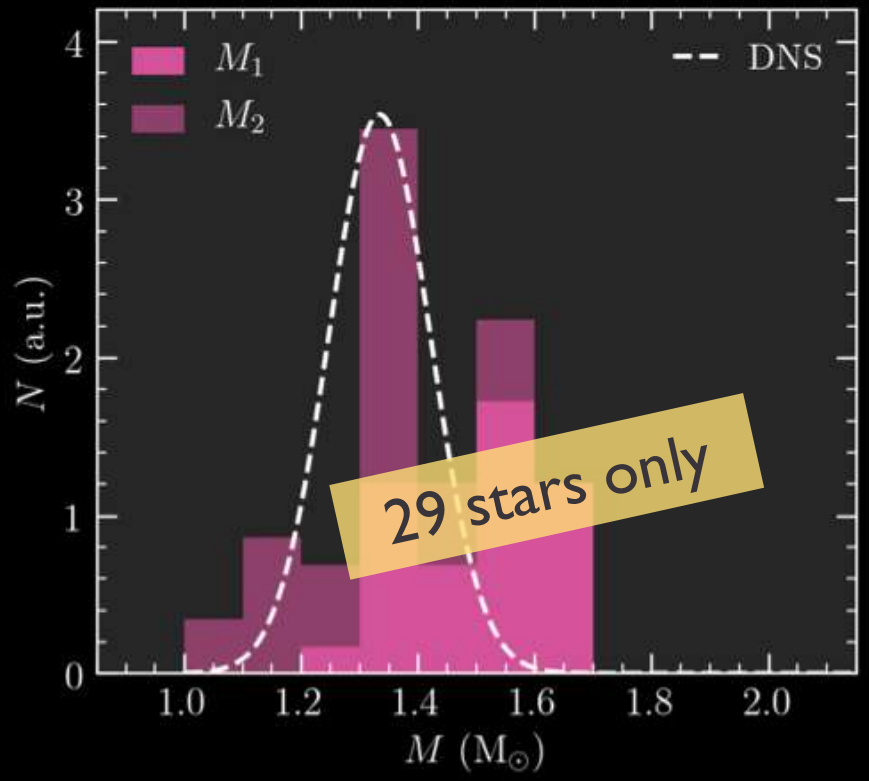




EMH+ (2021)

Assuming that **much of *r*-process material** came from NSMs, those *past* NS-NS systems are similar to *present-day* NS-NSs



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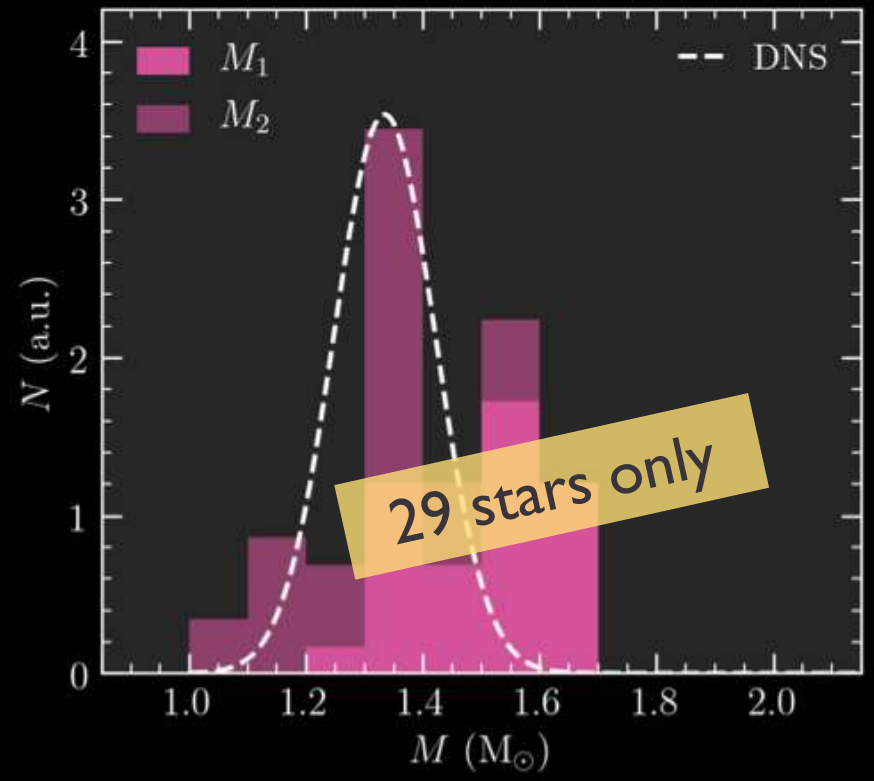

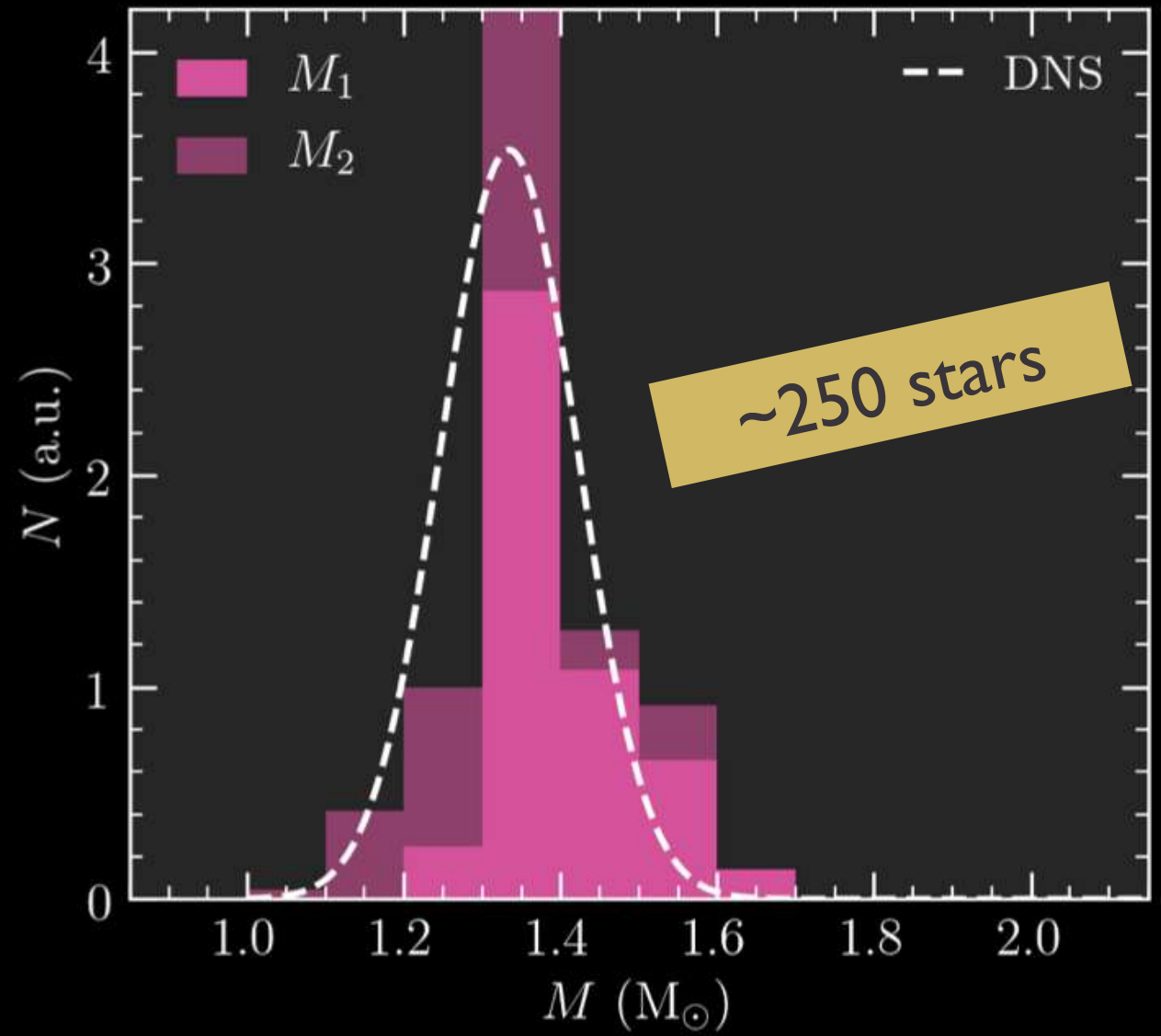

EMH+ (2021)

EMH+ 2021, ApJ, 909, 21

Summary & Implications

Differences in stellar abundances can be used
to study **specific merger conditions**

NSMs could be the **dominant source** of
r-process material in the MW

Inherently assuming that **all MP *r*-stars** have NSM origins

Implies that the **past** DNS population was
similar to the **present-day** distribution

This is not limited to *r*-process or even NSM studies...
Other stellar signatures (e.g., the *i*-process) exist!

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